THE DISCOVERY

OF

UCED ELECTRIC CURRENTS

VOLUME I

MEMOIRS BY JOSEPH HENRY

EDITED BY

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PREFACE

After the discovery by Oersted in the winter of 1819 of the influence of an electric current upon a magnet, many investigations were undertaken to study the connection between electricity and magnetism. Schweigger constructed a simple galvanometer in 1820; in the same year Arago and Davy showed that a steel sewing needle placed in a helix carrying a current became magnetized; in 1823 Ampère published his great memoir on the mechanical action between electric currents, which contains the results of his experiments begun in 1820 and his theory in explanation; and two years later Sturgeon constructed the first electro-magnet by winding a single coil of wire around a bar of soft iron bent into the form of a horse-shoe. This form of magnet was improved by Joseph Henry, who made what he called his "intensity" magnet by winding a continuous bobbin of many thicknesses around the bent iron bar, and his "quantity" magnet by placing several bobbins on the bar, in such a manner that they could all be joined "in parallel."

Both Henry and Faraday were engaged in a search for some method by which in the same manner as an electric current produced magnetism so magnetism could produce electricity. Henry was the first to discover and clearly appreciate such a process. In August 1829 he observed the production of sparks by extra-currents at breaking, and showed how they could be intensified by coiling the wire in a helix. In August of the following year, 1830, he observed that whenever a magnetic field was produced *or altered* inside a coil of wire there was induced an instantaneous current. He showed, further, the connection between these two phenomena: the spark and the induced current. These observations were not published until July 1832, for reasons which are well stated in a series of articles by his daughter, Miss Henry, in the *Electric Engineer* (New

York), Vol. XIII, 1892. Henry was, at the time of these discoveries, professor in the Albany Academy, one of the high-schools of the State of New York. He had at his disposal for experimental purposes one room and one month of the year, August. At other times he was occupied with teaching, and the room was required for lectures. He had to insulate his own wires, construct his own apparatus, and make all of the observations himself. Consequently he was obliged often to postpone for a year the completion of an investigation which was already begun. In this particular case, Henry undoubtedly discovered "Magneto-electricity" in 1829 and 1830, but, being unable to finish his experiments, delayed their publication. In August 1831 he was busy making new apparatus to use in the continuation of this investigation; but September 1 found it still unfinished. In June 1832 he received an account of Faraday's discoveries of the previous autumn and concluded to publish his own, however incomplete. Henry never publicly claimed the discovery of induced currents, always ascribing it to Faraday, because he was the first to publish his experiments.

Faraday was at this time professor in the Royal Institution in London, and had at his command all of its resources. He had tried for several years to produce electric currents from magnetism, but failed. In August 1831 he made an electromagnet on the general plan of Henry's "intensity magnet," a description of which he had seen; and on August 29, 1831, he began his famous "experimental researches in electricity" in the course of which he was soon led to discover the method of production of induced currents. On November 24 he read before the Royal Society a paper describing his discoveries. It was not until 1834 that he made any study of self-induction, his attention being called by Fleming Jenkin to the shock felt on breaking circuits.

Both Henry and Faraday recognized the fact that the intensity of induced currents varied directly as the strength of the magnetic field produced and inversely as the time taken to produce the change. But neither was able to state exactly the law which connects the various quantities. In 1834 Lenz expressed the relation in terms of Ampère's formula; and in 1845, F. Neumann stated the law as it is now known, $e = -\frac{dN}{\ldots}$

re e is the induced electromotive force, dN is the change in total magnetic induction in time dt. Helmholtz in his essay he "Conservation of Energy," Berlin 1847, and Lord Kelvin 1848 and 1851 showed that the production of induced curs was in accord with the principle of the Conservation of ergy. J. J. Thomson has, however, in his *Applications of amics to Physics and Chemistry,* London, 1888, p. 42, ed attention to the fact, "that when we have two circuits the nciple of the Conservation of Energy is not sufficient to uce the equations of motion, and that some other principle st be assumed implicitly in those proofs which profess to uce these equations by means of the Conservation of Energy ne."

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OHNS HOPKINS UNIVERSITY

GENERAL CONTENTS

On the Production of Currents and Sparks of Electricity from Magnetism

CONTENTS

On the Production of Currents and Sparks of Electricity from Magnetism

By JOSEPH HENRY

(Silliman's *American Journal of Science*, July 1832, Vol. XXII, pp. 403-408; *Scientific Writings*, Vol. I, p. 73.)

Although the discoveries of Oersted, Arago, Faraday, and others, have placed the intimate connection of electricity and magnetism in a most striking point of view, and although the theory of Ampère has referred all the phenomena of both these departments of science to the same general laws, yet until lately one thing remained to be proved by experiment, in order more fully to establish their identity; namely the possibility of producing electrical effects from magnetism. It is well known that surprising magnetic results can readily be obtained from electricity, and at first sight it might be supposed that electrical effects could with equal facility be produced from magnetism; but such has not been found to be the case, for although the experiment has often been attempted, it has nearly as often failed.

It early occurred to me that if galvanic magnets on my plan were substituted for ordinary magnets, in researches of this kind, more success might be expected. Besides their great powers these magnets possess other properties, which render them important instruments in the hands of the experimenter; their polarity can be instantaneously reversed, and their magnetism suddenly destroyed or called into full action, according as the occasion may require. With this view, I commenced, last August, the construction of a much larger galvanic magnet than, to my knowledge, had before been attempted, and also made preparations for a series of experiments with it on a large scale, in reference to the production of electricity from magnetism. I was, however, at that time accidentally interrupted in the pros-

resume them, until within the last few weeks, and then on a much smaller scale than was at first intended. In the meantime, it has been announced in the 117th number of the *Library of Useful Knowledge,* that the result so much sought after has at length been found by Mr. Faraday of the Royal Institution. It states that he has established the general fact, that when a piece of metal is moved in any direction, in front of a magnetic pole, electrical currents are developed in the metal, which pass in a direction at right angles to its own motion, and also that the application of this principle affords a complete and satisfactory explanation of the phenomena of magnetic rotation. No detail is given of the experiments, and it is somewhat surprising that results so interesting, and which certainly form a new era in the history of electricity and magnetism, should not have been more fully described before this time in some of the English publications; the only mention I have found of them is the following short account from the *Annals of Philosophy* for April, under the head of Proceedings of the Royal Institution:

"Feb. 17. — Mr. Faraday gave an account of the first two parts of his researches in electricity; namely, Volta-electric induction and magneto-electric induction. If two wires, *A* and *B,* be placed side by side, but not in contact, and a Voltaic current be passed through *A,* there is instantly a current produced by induction in *B,* in the opposite direction. Although the principal current in *A* be continued, still the secondary current in *B* is not found to accompany it, for it ceases after the first moment, but when the principal current is stopped then there is a second current produced in *B,* in the opposite direction to that of the first produced by the inductive action, or in the same direction as that of the principal current.

"If a wire, connected at both extremities with a galvanometer, be coiled in the form of a helix around a magnet, no current of electricity takes place in it. This is an experiment which has been made by various persons hundreds of times, in the hope of evolving electricity from magnetism, and as in other cases in which the wishes of the experimenter and the facts are opposed to each other, has given rise to very conflicting conclusions. But if the magnet be withdrawn from or introduced into such a helix, a current of electricity is produced *whilst the*

the galvanometer. If a single wire be passed by a magnetic pole, a current* of electricity is induced through it which can be rendered sensible."

Before having any knowledge of the method given in the above account, I had succeeded in producing electrical effects in the following manner, which differs from that employed by Mr. Faraday, and which appears to me to develop some new and interesting facts. A piece of copper wire, about thirty feet long and covered with elastic varnish, was closely coiled around the middle of the soft iron armature of the galvanic magnet described in Vol. XIX of the *American Journal of Science,* and which, when excited, will readily sustain between six hundred and seven hundred pounds. The wire was wound upon itself so as to occupy only about one inch of the length of the armature which is seven inches in all. The armature, thus furnished with the wire, was placed in its proper position across the ends of the galvanic magnet, and there fastened so that no motion could take place. The two projecting ends of the helix were dipped into two cups of mercury, and there connected with a distant galvanometer by means of two copper wires, each about forty feet long. This arrangement being completed, I stationed myself near the galvanometer and directed an assistant at a given word to immerse suddenly, in a vessel of dilute acid, the galvanic battery attached to the magnet. At the instant of immersion, the north end of the needle was deflected 30° to the west, indicating a current of electricity from the helix surrounding the armature. The effect however appeared only as a single impulse, for the needle, after a few oscillations, resumed its former undisturbed position in the magnetic meridian, although the galvanic action of the battery, and consequently the magnetic power was still continued. I was, however, much surprised to see the needle suddenly deflected from a state of rest to about 20° to the east, or in a contrary direction when the battery was withdrawn from the acid, and again deflected to the west when it was re-immersed. This operation was repeated many times in succession, and uniformly with the same result, the armature the whole time remaining immovably attached to the poles of the magnet, no motion being required to produce the effect, as

* *Phil. Mag.*, and *Annals of Philosophy*, April, 1832; vol. XI, p. 300.

it appeared to take place only in consequence of the instantaneous development of the magnetic action in one, and the sudden cessation of it in the other.*

This experiment illustrates most strikingly the reciprocal action of the two principles of electricity and magnetism, if indeed it does not establish their absolute identity. In the first place, magnetism is developed in the soft iron of the galvanic magnet by the action of the currents of electricity from the battery, and secondly the armature, rendered magnetic by contact with the poles of the magnet, induces in its turn currents of electricity in the helix which surrounds it; we have thus as it were electricity converted into magnetism and this magnetism again into electricity.

Another fact was observed which is somewhat interesting inasmuch as it serves in some respects to generalize the phenomena. After the battery had been withdrawn from the acid, and the needle of the galvanometer suffered to come to a state of rest after the resulting deflection, it was again deflected in the same direction by partially detaching the armature from the poles of the magnet to which it continued to adhere from the action of the residual magnetism, and in this way, a series of deflections, all in the same direction, was produced by merely slipping off the armature by degrees until the contact was entirely broken. The following extract from the register of the experiments exhibits the relative deflections observed in one experiment of this kind.

At the instant of immersion of the battery,	deflection	40° west.
At the instant of emersion of the battery,	"	18° east.
Armature partially detached,	"	7° east.
Armature entirely detached,	"	12° east.

The effect was reversed in another experiment, in which the needle was turned to the west in a series of deflections by dipping the battery but a small distance into the acid at first and afterwards immersing it by degrees.

From the foregoing facts it appears that a current of electricity is produced, for an instant, in a helix of copper wire surrounding a piece of soft iron whenever magnetism is induced

* [*This experiment was performed, at the latest, in August 1831, and most*

in the iron; and a current in an opposite direction when the magnetic action ceases; also that an instantaneous current in one or the other direction accompanies every change in the magnetic intensity of the iron.

Since reading the account before given of Mr. Faraday's method of producing electrical currents I have attempted to combine the effects of motion and induction; for this purpose a rod of soft iron ten inches long and one inch and a quarter in diameter, was attached to a common turning lathe, and surrounded with four helices of copper wire in such a manner that it could be suddenly and powerfully magnetized, while in rapid motion, by transmitting galvanic currents through three of the helices; the fourth being connected with the distant galvanometer was intended to transmit the current of induced electricity; all the helices were stationary while the iron rod revolved on its axis within them. From a number of trials in succession, first with the rod in one direction, then in the opposite, and next in a state of rest, it was concluded that no perceptible effect was produced on the intensity of the *magneto-electric* current by a rotary motion of the iron combined with its sudden magnetization.

The same apparatus, however, furnished the means of measuring separately the relative power of motion and induction in producing electrical currents. The iron rod was first magnetized by currents through the helices attached to the battery and while in this state one of its ends was quickly introduced into the helix connected with the galvanometer; the deflection of the needle in this case was seven degrees. The end of the rod was next introduced into the same helix while in its natural state and then suddenly magnetized; the deflection in this instance amounted to thirty degrees, showing a great superiority in the method of induction.

The next attempt was to increase the *magneto-electric* effect while the magnetic power remained the same, and in this I was more successful. Two iron rods six inches long and one inch in diameter, were each surrounded by two helices and then placed perpendicularly on the face of the armature, and between it and the poles of the magnet, so that each rod formed as it were a prolongation of the poles, and to these the armature adhered

rent from one helix produced a deflection of thirty-seven degrees; from two helices both on the same rod fifty-two degrees, and from three fifty-nine degrees; but when four helices were used, the deflection was only fifty-five degrees, and when to these were added the helix of smaller wire around the armature, the deflection was no more than thirty degrees. This result may perhaps have been somewhat affected by the want of proper insulation in the several spires of the helices; it however establishes the fact that an increase in the electric current is produced by using at least two or three helices instead of one. The same principle was applied to another arrangement which seems to afford the maximum of electric development from a given magnetic power; in place of the two pieces of iron and the armature used in the last experiments, the poles of the magnet were connected by a single rod of iron, bent into the form of a horse-shoe, and its extremities filed perfectly flat so as to come in perfect contact with the faces of the poles; around the middle of the arch of this horse-shoe, two strands of copper wire were tightly coiled one over the other. A current from one of these helices deflected the needle one hundred degrees, and when both were used the needle was deflected with such force as to make a complete circuit. But the most surprising effect was produced when instead of passing the current through the long wires to the galvanometer, the opposite ends of the helices were held nearly in contact with each other, and the magnet suddenly excited; in this case a small but vivid spark was seen to pass between the ends of the wires, and this effect was repeated as often as the state of intensity of the magnet was changed.

In these experiments the connection of the battery with the wires from the magnet was not formed by soldering, but by two cups of mercury which permitted the galvanic action on the magnet to be instantaneously suspended and the polarity to be changed and rechanged without removing the battery from the acid; a succession of vivid sparks was obtained by rapidly interrupting and forming the communication by means of one of these cups; but the greatest effect was produced when the magnetism was entirely destroyed and instantaneously reproduced by a change of polarity.

It appears from the May number of the *Annals of Philosophy*

sparks from the magnet by Mr. James D. Forbes of Edinburgh, who obtained a spark on the 30th of March; my experiments being made during the last two weeks of June. A simple notification of his result is given, without any account of the experiment, which is reserved for a communication to the Royal Society of Edinburgh; my result is therefore entirely independent of his and was undoubtedly obtained by a different process.

Electrical self-induction in a long helical wire

I have made several other experiments in relation to the same subject, but which more important duties will not permit me to verify in time for this paper. I may however mention one fact which I have not seen noticed in any work, and which appears to me to belong to the same class of phenomena as those before described; it is this: when a small battery is moderately excited by diluted acid, and its poles which should be terminated by cups of mercury, are connected by a copper wire not more than a foot in length, no spark is perceived when the connection is either formed or broken; but if a wire thirty or forty feet long be used instead of the short wire, though no spark will be perceptible when the connection is made, yet when it is broken by drawing one end of the wire from its cup of mercury, a vivid spark is produced. If the action of the battery be very intense, a spark will be given by the short wire; in this case it is only necessary to wait a few minutes until the action partially subsides, and until no more sparks are given from the short wire; if the long wire be now substituted a spark will again be obtained. The effect appears somewhat increased by coiling the wire into a helix; it seems also to depend in some measure on the length and thickness of the wire. I can account for these phenomena only by supposing the long wire to become charged with electricity, which by its re-action on itself projects a spark when the connection is broken.*

* [*This experiment was performed in August* 1829.]

On the Influence of a Spiral Conductor in Increasing the Intensity of Electricity from a Galvanic Arrangement of a Single Pair, etc.

CONTENTS

Contributions to Electricity and Magnetism

No. II

On the Influence of a Spiral Conductor in Increasing the Intensity of Electricity from a Galvanic Arrangement of a Single Pair, etc.

By JOSEPH HENRY

(*Transactions American Philosophical Society,* n. s., Vol. V. pp. 223–231, read February 6, 1835; *Scientific Writings,* Vol. I, p. 92.)

In the *American Journal of Science* for July 1832, I announced a fact in Galvanism which I believe had never before been published. The same fact, however, appears to have been since observed by Mr. Faraday, and has lately been noticed by him in the November number of the *London and Edinburgh Journal of Science* for 1834.

The phenomenon as described by me is as follows: "When a small battery is moderately excited by diluted acid, and its poles, terminated by cups of mercury, are connected by a copper wire not more than a foot in length, no spark is perceived when the connection is either formed or broken; but if a wire thirty or forty feet long be used instead of the short wire, though no spark will be perceptible when the connection is made, yet when it is broken by drawing one end of the wire from its cup of mercury, a vivid spark is produced. If the action of the battery be very intense, a spark will be given by a short wire; in this case it is only necessary to wait a few minutes until the action partially subsides, and until no more sparks are given from the wire; if the long wire be now substituted a spark will be again obtained. The effect appears somewhat increased by coiling the wire into a helix; it seems also to depend in some measure on the length and thickness of the wire. I can account for these phenomena only by supposing the long wire to become

charged with electricity, which by its re-action on itself projects a spark when the connection is broken."*

The above was published immediately before my removal from Albany to Princeton, and new duties interrupted for a time the further prosecution of the subject. I have, however, been able during the past year to resume in part my investigations, and among others, have made a number of observations and experiments which develop some new circumstances in reference to this curious phenomenon.

These, though not as complete as I could wish, are now presented to the Society, with the belief that they will be interesting at this time on account of the recent publication of Mr. Faraday on the same subject.

The experiments are not given in the precise order in which they were first made, but in that which I deem best suited to render them easily understood; they have, however, been repeated for publication in almost the same order in which they are here given.

1. A galvanic battery, consisting of a single plate of zinc and copper, and exposing one and a half square feet of zinc surface, including both sides of the plate, was excited with diluted sulphuric acid and then permitted to stand until the intensity of the action became nearly constant. The poles connected by a piece of copper bell-wire of the ordinary size and five inches long, gave no spark when the contact was broken.

2. A long portion of wire, from the same piece with that used in the last experiment, was divided into equal lengths of fifteen feet, by making a loop at each division, which could be inserted into the cups of mercury on the poles of the battery. These loops being amalgamated and dipped in succession into one of the cups while the first end of the wire constantly remained in the other, the effect was noted. The first length, or fifteen feet, gave a very feeble spark, which was scarcely perceptible. The second, or thirty feet, produced a spark a little more intense, and the effect constantly increased with each additional length until one hundred and twenty feet were used; beyond this there was no perceptible increase; and a wire of two hundred and forty feet gave a spark of rather less intensity. From other observations I infer that the length necessary to produce a

maximum result, varies with the intensity of the action of the battery, and also with its size.

3. With equal lengths of copper wire of unequal diameters, the effect was greater with the larger; this also appears to depend in some degree on the size of the battery.

4. A length of about forty feet of the wire used in experiments first and second was covered with silk and coiled into a cylindrical helix of about two inches in height and the same in diameter. This gave a more intense spark than the same wire when uncoiled.

5. A ribbon of sheet copper nearly an inch wide, and twenty-eight and a half feet long, was covered with silk, and rolled into a flat spiral similar to the form in which woolen binding is found in commerce. With this a vivid spark was produced, accompanied by a loud snap. The same ribbon uncoiled gave a feeble spark similar in intensity to that produced by the wire in experiment third. When coiled again the snap was produced as at first. This was repeated many times in succession, and always with the same result.

6. To test still farther the influence of coiling, a second ribbon was procured precisely similar in length and in all other respects to the one used in the last experiment. The effect was noted with one of these coiled into a flat spiral and the other uncoiled, and again with the first uncoiled and the second coiled. When uncoiled each gave a feeble spark of apparently equal intensity, when coiled, a loud snap. One of these ribbons was next doubled into two equal strands, and then rolled into a double spiral with the point of doubling at the centre. By this arrangement, the electricity, in passing through the spiral, would move in opposite directions in each contiguous spire, and it was supposed that in this case the opposite actions which might be produced would neutralize each other. The result was in accordance with the anticipation; the double spiral gave no spark whatever, while the other ribbon coiled into a single spiral produced as before a loud snap. Lest the effect might be due to some accidental touching of the different spires, the double spiral was covered with an additional coating of silk, and also the other ribbon was coiled in the same manner; the effect with both was the same.

7. In order to increase if possible the intensity of the spark

while the battery remained the same, larger spirals were applied in succession. The effect was increased until one of ninety-six feet long, an inch and a half wide and weighing fifteen pounds was used. The snap from this was so loud that it could be distinctly heard in an adjoining room with the intervening door closed. Want of materials has prevented me from trying a larger spiral conductor than this, but it is probable that there is a length which, with a given quantity and intensity of galvanism, would produce a maximum effect. When the size of the battery is increased, a much greater effect is produced with the same spiral. Thus when the galvanic apparatus, described in the first article, is arranged as a "calorimotor" of eight pairs, the snap produced on breaking contact, with the spiral last described, resembled the discharge of a small Leyden jar highly charged.

8. A handle of thick copper was soldered on each end of the large spiral at right angles to the ribbon similar to those attached to the wires in Pixii's magneto-electric machine for giving shocks. When one of these was grasped by each hand, and the contact broken, a shock was received which was felt at the elbows, and this was repeated as often as the contact was broken. This shock is rather a singular phenomenon, since it appears to be produced by a lateral discharge, and it is therefore important to determine its direction in reference to the primary current.

9. A shock is also received when the copper of the battery is grasped by one hand, and the handle attached to the copper pole of the ribbon with the other. This may be called the direct shock, since it is produced by a part of the direct current. It is, however, far less intense than that produced by the lateral discharge.

10. When the poles were joined by two coils, connected by a cup of mercury between them, a spark was produced by breaking the circuit at the middle point, and when a pair of platina wires was introduced into the circuit with the large coil and immersed in a solution of acid, decomposition took place in the liquid at each rupture of contact, as was shown by a bubble of gas given off at each wire. It must be recollected that the shocks and the decomposition here described were produced by the electricity

11. The contact with the poles of the battery and the large spiral being broken in a vessel containing a mixture of hydrogen and atmospheric air, an explosion was produced.

I should also mention that the spark is generally attended with a deflagration of the mercury, and that when the end of the spiral is brought in contact with the edge of the copper cup or the plate of the battery, a vivid deflagration of the metal takes place. The sides of the cup sometimes give a spark when none can be drawn from the surface of the mercury. This circumstance requires to be guarded against when experimenting on the comparative intensities of sparks from different arrangements. If the battery formerly described be arranged as a "calorimotor" and one end of a large spiral conductor be attached to one pole, and the other end drawn along the edge of the connector, a series of loud and rapid explosions is produced, accompanied by a brilliant deflagration of the metal, and this takes place when the excitement of the battery is too feeble to heat to redness a small platina wire.

12. A number of experiments were made to determine the effect of introducing a cylinder of soft iron into the axis of the flat spiral, in reference to the shock, the spark, etc., but no difference could be observed with the large spiral conductor; the effect of the iron was merged in that of the spiral. When, however, one of the smaller ribbons was formed into a hollow cylindrical helix of about nine inches long, and a cylinder of soft iron an inch and a half in diameter was inserted, the spark appeared a little more intense than without the iron. The obliquity of the spires in this case was unfavorable to their mutual action, while the magnetism was greater than with the flat spiral, since the conductor closely surrounded the whole length of the cylinder.

I would infer from these experiments, that some effects heretofore attributed to magneto-electric action are chiefly due to the reaction on each other of the several spires of the coil which surround the magnet.

13. One of the most singular results in this investigation was first obtained in operating with the large galvanic battery. The whole instrument was arranged as a "calorimotor" of eight pairs, and a large spiral conductor introduced into the circuit at *c d*, while a piece of thick copper wire about five inches long,

united the poles at *a b*. In this state an explosion or loud snap was produced, not only when the contact was broken at the spiral, but also when one end of the short wire, at the other extremity of the apparatus, was drawn from its cup. All the other short movable connectors of the battery gave a similar result. When the spiral was removed from the circuit, and a short wire substituted, no effect of the kind was produced. From this experiment it appears that the influence of the spiral is exerted through at least eight alternations of zinc, acid, and copper, and thus gives to a short wire, at the other extremity of the circuit, the power of producing a spark.

14. The influence of the coil was likewise manifest when the zinc and copper plates of a single pair were separated from each other to the distance of fourteen inches in a trough without partitions, filled with diluted acid. Although the electrical intensity in this case must have been very low, yet there was but little reduction in the apparent intensity of the spark.

The spiral conductor produces, however, little or no increase of effect when introduced into a galvanic circuit of considerable intensity. Thus when the large spiral used in experiments seven, eight, etc., was made to connect the poles of two Cruickshanks troughs, each containing fifty-six four-inch plates, no greater effect was perceived than with a short thick wire; in both cases in making the contact a feeble spark was given, attended with a slight deflagration of the mercury. The batteries at the same time were in sufficiently intense action to give a disagreeable shock. It is probable, however, that if the length of the coil were increased in some proportion to the increase of intensity, an increased effect would still be produced.

In operating with the apparatus described in the last experiment, a phenomenon was observed in reference to the action of the battery itself, which I do not recollect to have seen mentioned, although it is intimately connected with the facts of Magneto-electricity, as well as with the subject of these investigations, viz.: When the body is made to form a part of a galvanic circuit composed of a number of elements, a shock is of course felt at the moment of completing the circuit. If the battery be not very large, little or no effect will be perceived during the uninterrupted circulation of the galvanic current;

point, a shock will be felt at the moment, nearly as intense as that given when the contact was first formed. The secondary shock is rendered more evident, when the battery is in feeble action, by placing in the mouth the end of one of the wires connected with the poles; a shock and flash of light will be perceived when the circuit is completed, and also the same when the contact is broken at any point, but nothing of the kind will be perceived in the intermediate time, although the circuit may continue uninterrupted for some minutes. This I consider an important fact in reference to the action of the voltaic current.

The phenomena described in this paper appear to be intimately connected with those of Magneto-electricity, and this opinion I advanced with the announcement of the first fact of these researches in the *American Journal of Science*. They may I conceive be all referred to that species of dynamical *Induction* discovered by Mr. Faraday, which produces the following phenomenon, namely: when two wires, *A* and *B*, are placed side by side, but not in contact, and a voltaic current is passed through *A*, there is a current produced in *B*, but in an opposite direction. The current in *B* exists only for an instant, although the current in *A* may be indefinitely continued; but if the current in *A* be stopped, there is produced in *B* a second current, in an opposite direction, however, to the first current.

The above fundamental fact in Magneto-electricity appears to me to be a direct consequence of the statical principles of "*Electrical Induction*" as mathematically investigated by Cavendish, Poisson, and others. When the two wires *A* and *B* are in their natural state, an equilibrium is sustained by the attractions and repulsions of the two fluids in each wire; or, according to the theory of Franklin and Cavendish, by the attractions and repulsions of the one fluid, and the matter of the two wires. If a current of free electricity be passed through *A*, the natural equilibrium of *B* will be disturbed for an instant, in a similar manner to the disturbance of the equilibrium in an insulated conductor, by the sudden addition of fluid, to a contiguous conductor. On account of the repulsive action of the fluid, the current in *B* will have an opposite direction to that in *A*; and if the intensity of action remains constant, a new state of equilibrium will be assumed. The second

state of *B*, however, may perhaps be regarded as one of tension, and as soon as the extra action ceases in it, the fluid in *B* will resume its natural state of distribution, and thus a returning current for an instant be produced.

The action of the spiral conductor in producing sparks is but another case of the same action; for since action and reaction are equal and in contrary directions, if a current established in *A* produces a current in an opposite direction in *B*, then a current transmitted through *B* should accelerate or increase the intensity of a current already existing in the same direction in *A*. In this way the current in the several successive spires of the coil may be conceived to accelerate, or to tend to accelerate, each other; and when the contact is broken, the fluid of the first spire is projected from it with intensity by the repulsive action of the fluid in all the succeeding spires.

In the case of the double spiral conductor, in experiment six, the fluid is passing in an opposite direction; and according to the same views, a retardation or decrease of intensity should take place.

The phenomenon of the secondary shock with the battery appears to me to be a consequence of the law of Mr. Faraday. The parts of the human body contiguous to those through which the principal current is passing, may be considered as in the state of the second wire *B*; when the principal current ceases, a shock is produced by the returning current of the natural electricity of the body.

If this explanation be correct, the same principle will readily account for a curious phenomenon discovered several years since by Savary, but which I believe still remains an isolated fact. When a current is transmitted through a wire, and a number of small needles are placed transverse to it, but at different distances, the direction of the magnetic polarity of the needles varies with their distance from the conducting wire. The action is also periodical; diminishing as the distance increases, until it becomes zero; the polarity of the needles is then inverted, acquires a maximum, decreases to zero again, and then resumes the first polarity; several alternations of this kind being observed.* Now this is precisely what would take place if we suppose that the

* Cumming's *Demonferrand*, p. 247; also *Edinburgh Journal of Science*

principal current induces a secondary one in an opposite direction in the air surrounding the conductor, and this again another in an opposite direction at a great distance, and so on. The needles at different distances would be acted on by the different currents, and thus the phenomena described be produced.

The action of the spiral is also probably connected with the fact in common electricity called the lateral discharge: and likewise with an appearance discovered some years since by Nobili, of a vivid light, produced when a Leyden jar is discharged through a flat spiral.

The foregoing views are not presumed to be given as exhibiting the actual operation of nature in producing the phenomena described, but rather as the hypotheses which have served as the basis of my investigations, and which may further serve as formulæ from which to deduce new consequences to be established or disproved by experiment.

Many points of this subject are involved in an obscurity which requires more precise and extended investigation; we may, however, confidently anticipate much additional light from the promised publication of Mr. Faraday's late researches in this branch of science.

CONTENTS

Contributions to Electricity and Magnetism

No. III

On Electro-Dynamic Induction

By JOSEPH HENRY

(*Transactions American Philosophical Society,* n. s., Vol. VI, pp. 303–337, read November 2, 1838; *Scientific Writings,* Vol. 1, p. 108.)

Introduction

1. Since my investigations in reference to the influence of a spiral conductor, in increasing the intensity of a galvanic current, were submitted to the Society, the valuable paper of Dr. Faraday, on the same subject, has been published, and also various modifications of the principle have been made by Sturgeon, Masson, Page, and others, to increase the effects. The spiral conductor has likewise been applied by Cav. Antinori to produce a spark by the action of a thermo-electrical pile; and Mr. Watkins has succeeded in exhibiting all the phenomena of hydro-electricity by the same means. Although the principle has been much extended by the researches of Dr. Faraday, yet I am happy to state that the results obtained by this distinguished philosopher are not at variance with those given in my paper.

2. I now offer to the Society a new series of investigations in the same line, which I hope may also be considered of sufficient importance to merit a place in the Transactions.

3. The primary object of these investigations was to discover, if possible, inductive actions in common electricity analogous to those found in galvanism. For this purpose a series of experiments was commenced in the spring of 1836, but I was at that time diverted, in part, from the immediate object of my research, by a new investigation of the phenomenon known in common electricity by the name of the lateral discharge. Circum-

stances prevented my doing anything further, in the way of experiment, until April last, when most of the results which I now offer to the Society were obtained. The investigations are not as complete in several points as I could wish, but as my duties will not permit me to resume the subject for some months to come, I therefore present them as they are; knowing, from the interest excited by this branch of science in every part of the world, that the errors which may exist will soon be detected, and the truths be further developed.

4. The experiments are given nearly in the order in which they were made; and in general they are accompanied by the reflections which led to the several steps of the investigation. The whole series is divided, for convenience of arrangement, into six sections, although the subject may be considered as consisting, principally, of two parts, the first relating to a new examination of the induction of galvanic currents, and the second to the discovery of analogous results in the discharge of ordinary electricity.

5. The principal articles of apparatus used in the experiment consist of a number of flat coils of copper ribbon, which will be designated by the names of coil No. 1, coil No. 2, etc.; also of

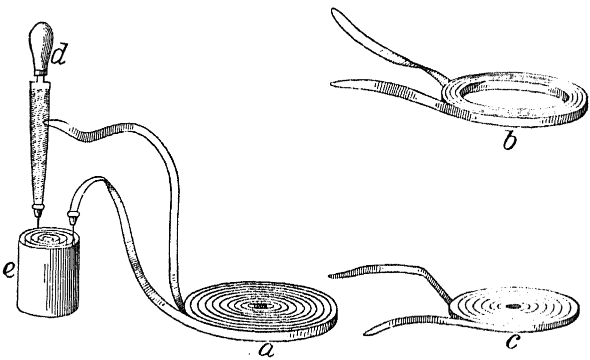

FIG. 1.—*a* represents coil No. 1, *b* coil No. 2, and *c* coil No. 3; *e* the battery, *d* the rasp.

several coils of long wire; and these, to distinguish them from the ribbons, will be called helix No. 1, helix No. 2, etc.

6. Coil No. 1 is formed of thirteen pounds of copper plate, one inch and a half wide and ninety-three feet long. It is well

covered with two coatings of silk, and was generally used in the form represented in Fig. 1, which is that of a flat spiral sixteen inches in diameter. It was, however, sometimes formed into a ring of larger diameter, as is shown in Fig. 4, Section III.

7. Coil No. 2 is also formed of copper plate, of the same width and thickness as coil No. 1. It is, however, only sixty feet long. Its form is shown at *b*, Fig. 1. The opening at the centre is sufficient to admit helix No. 1. Coils Nos. 3, 4, 5, 6, etc. are all about sixty feet long, and of copper plate of the same thickness, but of half the width of coil No. 1.

8. Helix No. 1 consists of sixteen hundred and sixty yards of copper wire 1/49th of an inch in diameter, No. 2 of nine hun-

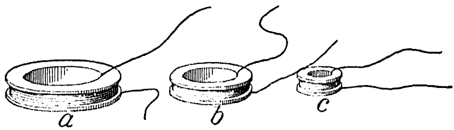

Fig. 2.—*a* represents helix No. 1, *b* helix No. 2, *c* helix No. 3.

dred and ninety yards, and No. 3 of three hundred and fifty yards, of the same wire. These helices are shown in Fig. 2, and are so adjusted in size as to fit into each other, thus forming one long helix of three thousand yards: or by using them separately, and in different combinations, seven helices of different lengths. The wire is covered with cotton thread, saturated with beeswax, and between each stratum of spires a coating of silk is interposed.

9. Helix No. 4 is shown at *a*, Fig. 4, Section III; it is formed of five hundred and forty-six yards of wire, 1/49th of an inch in diameter, the several spires of which are insulated by a coating of cement. Helix No. 5 consists of fifteen hundred yards of silvered copper wire, 1/125th of an inch in diameter, covered with cotton, and is of the form of No. 4.

10. Besides these I was favored with the loan of a large spool of copper wire covered with cotton, 1/16th of an inch in diameter, and five miles long. It is wound on a small axis of iron, and forms a solid cylinder of wire, eighteen inches long and thirteen in diameter.

11. For determining the direction of induced currents, a magnetizing spiral was generally used, which consists of about thirty

spires of copper wire, in the form of a cylinder, and so small as just to admit a sewing needle into the axis.

12. Also a small horseshoe is frequently referred to, which is formed of a piece of soft iron, about three inches long, and 2/5ths of an inch thick; each leg is surrounded with about five feet of copper bell wire. This length is so small that only a current of electricity of considerable quantity can develop the magnetism of the iron. The instrument is used for indicating the existence of such a current.

13. The battery used in most of the experiments is shown in Fig. 1. It is formed of three concentric cylinders of copper, and two interposed cylinders of zinc. It is about eight inches high, five inches in diameter, and exposes about one square foot and three quarters of zinc surface, estimating both sides of the metal. In some of the experiments a larger battery was used, weakly charged, but all the results mentioned in the paper except those with a Cruickshank trough, can be obtained with one or two batteries of the above size, particularly if excited by a strong solution. The manner of interrupting the circuit of the conductor by means of a rasp, *b*, is shown in the same figure.

SECTION 1

Conditions which Influence the Induction of a Current on itself

14. The phenomenon of the spiral conductor is at present known by the name of the induction of a current on itself, to distinguish it from the induction of the secondary current, discovered by Dr. Faraday. The two, however, belong to the same class, and experiments render it probable that the spark given by the long conductor is, from the natural electricity of the metal, disturbed for an instant by the induction of the primary current. Before proceeding to the other parts of these investigations, it is important to state the results of a number of preliminary experiments made to determine more definitely the conditions which influence the action of the spiral conductor.

15. When the electricity is of low intensity, as in the case of the thermo-electrical pile, or a large single battery weakly excited with dilute acid, the flat ribbon coil No. 1, ninety-three

the loudest snaps from a surface of mercury. The shocks, with this arrangement, are, however, very feeble, and can only be felt in the fingers or through the tongue.

16. The induced current in a short coil, which thus produces deflagration, but not shocks, may, for distinction, be called one of quantity.

17. When the length of the coil is increased, the battery continuing the same, the deflagrating power decreases, while the intensity of the shock continually increases. With five ribbon coils making an aggregate length of three hundred feet, and the small battery, Fig. 1, the deflagration is less than with coil No. 1, but the shocks are more intense.

18. There is, however, a limit to this increase of intensity of the shock, and this takes place when the increased resistance or diminished conduction of the lengthened coil begins to counteract the influence of the increasing length of the current. The following experiment illustrates this fact. A coil of copper wire, 1/16th of an inch in diameter, was increased in length by successive additions of about thirty-two feet at a time. After the first two lengths, or sixty-four feet, the brilliancy of the spark began to decline, but the shocks constantly increased in intensity, until a length of five hundred and seventy-five feet was obtained, when the shocks also began to decline. This was then the proper length to produce the maximum effect with a single battery, and a wire of the above diameter.

19. When the intensity of the electricity of the battery is increased, the action of the short ribbon coil decreases. With a Cruickshank's trough of sixty plates, four inches square, scarcely any peculiar effect can be observed when the coil forms a part of the circuit. If, however, the length of the coil be increased in proportion to the intensity of the current, then the inductive influence becomes apparent. When the current, from ten plates of the above-mentioned trough, was passed through the wire of the large spool (10), the induced shock was too severe to be taken through the body. Again, when a small trough of twenty-five one-inch plates, which alone would give but a very feeble shock, was used with helix No. 1, an intense shock was received from the induction, when the contact was broken. Also a slight shock in this arrangement is given when the contact is formed, but it is very feeble in comparison with the other. The spark,

however, with the long wire and compound battery is not as brilliant as with the single battery and the short ribbon coil.

20. When the shock is produced from a long wire, as in the last experiments, the size of the plates of the battery may be very much reduced, without a corresponding reduction of the intensity of the shock. This is shown in an experiment with the large spool of wire (10). A very small compound battery was formed of six pieces of copper bell-wire, about one inch and a half long, and an equal number of pieces of zinc of the same size. When the current from this was passed through the five miles of the wire of the spool, the induced shock was given at once to twenty-six persons joining hands. This astonishing effect placed the action of a coil in a striking point of view.

21. With the same spool and the single battery used in the former experiments, no shock, or at most a very feeble one, could be obtained. A current, however, was found to pass through the whole length, by its action on the galvanometer; but it was not sufficiently powerful to induce a current which could counteract the resistance of so long a wire.

22. The induced current in these experiments may be considered as one of *considerable "intensity"* and *small "quantity."*

23. The form of the coil has considerable influence on the intensity of the action. In the experiments of Dr. Faraday, a long cylindrical coil of thick copper wire, inclosing a rod of soft iron, was used. This form produces the greatest effect when magnetic reaction is employed; but in the case of simple galvanic induction I have found the form of the coils and helices represented in the figures most effectual. The several spires are more nearly approximated, and therefore they exert a greater mutual influence. In some cases, as will be seen hereafter, the ring form shown in Fig. 4, is most effectual.

24. In all cases the several spires of the coil should be well insulated, for although in magnetizing soft iron, and in analogous experiments the touching of two spires is not attended with any great reduction of action; yet in the case of the induced current, as will be shown in the progress of these investigations, a single contact of two spires is sometimes sufficient to neutralize the whole effect.

25. It must be recollected that all the experiments with these

the reaction of iron temporarily magnetized; since the introduction of this would in some cases interfere with the action, and render the results more complex.

Section 2

Conditions which Influence the Production of Secondary Currents

26. The secondary currents, as it is well known, were discovered in the introduction of magnetism and electricity by Dr. Faraday, in 1831. But he was at that time urged to the exploration of new and apparently richer veins of science, and left this branch to be traced by others. Since then, however, attention has been almost exclusively directed to one part of the subject, namely, the induction from magnetism, and the perfection of the magneto-electrical machine: and I know of no attempts except my own to review and extend the purely electrical part of Dr. Faraday's admirable discovery.

27. The energetic action of the flat coil, in producing the induction of a current on itself, led me to conclude that it would also be the most proper means for the exhibition and study of the phenomena of the secondary galvanic currents.

28. For this purpose coil No. 1 was arranged to receive the current from the small battery, and coil No. 2 placed on this, with a plate of glass interposed to insure perfect insulation; as often as the circuit of No. 1 was interrupted, a powerful secondary current was induced in No. 2. The arrangement is the same as that exhibited in Fig. 3, with the exception that in this the compound helix is represented as receiving the induction, instead of coil No. 2.

29. When the ends of the second wire were rubbed together, a spark was produced at the opening. When the same ends were joined by the magnetizing spiral (11), the enclosed needle became strongly magnetic. Also when the secondary current was passed through the wires of the iron horseshoe (12), magnetism was developed; and when the ends of the second coil were attached to a small decomposing apparatus, of the kind which

was given off at each pole. The shock, however, from this coil is very feeble, and can scarcely be felt above the fingers.

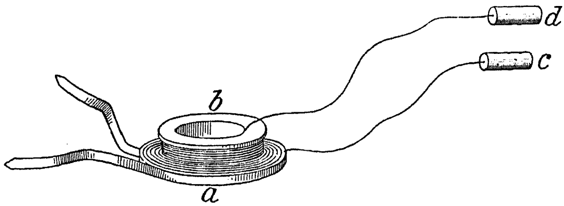

FIG. 3. — *a* represents coil No. 1, *b* helix No. 1, and *c*, *d*, handles for receiving the shock.

30. This current has therefore the properties of one of moderate "intensity" but considerable "quantity."

31. Coil No. 1 remaining as before, a longer coil, formed by uniting Nos. 3, 4, and 5, was substituted for No. 2. With this arrangement, the spark produced when the ends were rubbed together, was not as brilliant as before; the magnetizing power was much less; decomposition was nearly the same, but the shocks were more powerful, or in other words the "intensity" of the induced current was increased by an increase of the length of the coil, while the "quantity" was apparently decreased.

32. A compound helix, formed by uniting Nos. 1 and 2, and therefore containing two thousand six hundred and fifty yards of wire, was next placed on coil No. 1. The weight of this helix happened to be precisely the same as that of coil No. 2, and hence the different effects of the same quantity of metal in the two forms of a long and short conductor, could be compared. With this arrangement the magnetizing effects with the apparatus before mentioned, disappeared. The sparks were much smaller, and also the decomposition less, than with the short coil; but the shock was almost too intense to be received with impunity, except through the fingers of one hand. A circuit of fifty-six of the students of the senior class, received it at once from a single rupture of the battery current, as if from the discharge of a Leyden jar weakly charged. The secondary current in this case was one of small quantity, but of great intensity.

33. The following experiment is important in establishing the

well as the power of decomposition, with a wire of a given diameter. Helix No. 5 which consists of wire only 1/125th of an inch in diameter, was placed on Coil No. 2, and its length increased to about seven hundred yards. With this extent of wire neither decomposition nor magnetism could be obtained, but shocks were given of a peculiarly pungent nature; they did not, however, produce much muscular action. The wire of the helix was further increased to about fifteen hundred yards; the shock was now found to be scarcely perceptible in the fingers.

34. As a counterpart to the last experiment, coil No. 1 was formed into a ring of sufficient internal diameter to admit the great spool of wire (11), and with the whole length of this (which, as has before been stated, is five miles) the shock was found so intense as to be felt at the shoulder, when passed only through the forefinger and thumb. Sparks and decomposition were also produced, and needles rendered magnetic. The wire of this spool is 1/16th of an inch thick, and we therefore see from this experiment, that by increasing the diameter of the wire, its length may also be much increased, with an increased effect.

35. The fact (33) that the induced current is diminished by a further increase of the wire, after a certain length has been attained, is important in the construction of the magneto-electrical machine, since the same effect is produced in the induction of magnetism. Dr. Goddard of Philadelphia, to whom I am indebted for coil No. 5, found that when its whole length was wound on the iron of a temporary magnet, no shocks could be obtained. The wire of the machine may therefore be of such a length, relative to its diameter, as to produce shocks but no decomposition; and if the length be still further increased, the power of giving shocks may also become neutralized.

36. The inductive action of coil No. 1, in the foregoing experiments, is precisely the same as that of a temporary magnet in the case of the magneto-electrical machine. A short thick wire around the armature gives brilliant deflagrations, but a long one produces shocks. This fact, I believe, was first discovered by my friend Mr. Saxton, and afterwards investigated by Sturgeon and Lentz.

37. We might at first sight conclude, from the perfect simi-

theory of Ampère, exist in the magnet, are like those in the short coil, of great quantity and feeble intensity; but succeeding experiments will show that this is not necessarily the case.

38. All the experiments given in this section have thus far been made with a battery of a single element. This condition was now changed, and a Cruickshank trough of sixty pairs substituted. When the current from this was passed through the ribbon coil No. 1, no indication, or a very feeble one, was given of a secondary current in any of the coils or helices, arranged as in the preceding experiments. The length of the coil, in this case, was not commensurate with the intensity of the current from the battery. But when the long helix, No. 1, was placed instead of coil No. 1, a powerful inductive action was produced on each of the articles, as before.

39. First, helices No. 2 and No. 3 were united into one, and placed within helix No. 1, which still conducted the battery current. With this disposition a secondary current was produced, which gave intense shocks but feeble decomposition, and no magnetism in the soft iron horseshoe. It was therefore one of intensity, and was induced by a battery current also of intensity.

40. Instead of the helix used in the last experiment for receiving the induction, one of the coils (No. 3) was now placed on helix No. 1, the battery remaining as before. With this arrangement the induced current gave no shocks, but it magnetized the small horseshoe; and when the ends of the coil were rubbed together, produced bright sparks. It had, therefore, the properties of a current of quantity, and it was produced by the induction of a current, from a battery, of intensity.

41. This experiment was considered of so much importance, that it was varied and repeated many times, but always with the same result; it therefore establishes the fact that *an "intensity" current can induce one of "quantity,"* and by the preceding experiments, the converse has also been shown, that *a "quantity" current can induce one of "intensity."*

42. This fact appears to have an important bearing on the law of the inductive action, and would seem to favor the supposition that the lower coil, in the two experiments with the long and short secondary conductors, exerted the same amount of inductive force, and that in one case this was expended (to use the language of theory) in giving a great velocity to a small

quantity of the fluid, and in the other in producing a slower motion in a larger current; but in the two cases were it not for the increased resistance to conduction in the longer wire, the quantity multiplied by the square of the velocity would be the same. This, however, is as yet a hypothesis, but it enables us to conceive how intensity and quantity may both be produced from the same induction.

43. From some of the foregoing experiments we may conclude that the quantity of electricity in motion in the helix is really less than in the coil, of the same weight of metal; but this may possibly be owing simply to the greater resistance offered by the longer wire. It would also appear, if the above reasoning be correct, that to produce the most energetic physiological effects, only a small quantity of electricity moving with great velocity, is necessary.

44. In this and the preceding section, I have attempted to give only the general conditions which influence the galvanic induction. To establish the law would require a great number of more refined experiments, and the consideration of several circumstances which would affect the results, such as the conduction of the wires, the constant state of the battery, the method of breaking the circuit with perfect regularity, and also more perfect means than we now possess of measuring the amount of the inductive action; all these circumstances render the problem very complex.

SECTION 3

On the Induction of Secondary Currents at a Distance

45. In the experiments given in the two preceding Sections, the conductor which received the inductions was separated from that which transmitted the primary current by the thickness only of a pane of glass; but the action from this arrangement was so energetic, that I was naturally led to try the effect at a greater distance.

46. For this purpose coil No. 1 was formed into a ring of about two feet in diameter, and helix No. 4 placed as is shown in the figure. When the helix was at the distance of about sixteen inches from the middle of the plane of the ring, shocks could be perceived through the tongue, and these rapidly in-

creased in intensity as the helix was lowered, and when it reached the plane of the ring they were quite severe. The effect, however, was still greater when the helix was moved from the centre to the inner circumference, as at *c;* but when

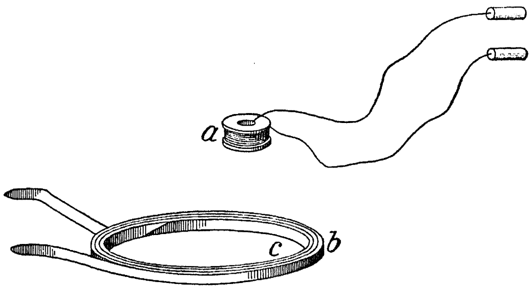

FIG. 4. — *a* represents helix No. 4, *b* coil No. 1, in the form of a ring.

it was placed without the ring, in contact with the outer circumference, at *b,* the shocks were very slight; and when placed within, but its axis at right angles to that of the ring, not the least effect could be observed.

47. With a little reflection, it will be evident that this arrangement is not the most favorable for exhibiting the induction at a distance, since the side of the ring, for example, at *c,* tends to produce a current revolving in one direction in the near side of the helix, and another in an opposite direction in the farther side. The resulting effect is therefore only the difference of the two, and in the position as shown in the figure; this difference must be very small since the opposite sides of the helix are approximately at the same distance from *c.* But the difference of action on the two sides constantly increases as the helix is brought near the side of the ring, and becomes a maximum when the two are in the position of internal contact. A helix of larger diameter would therefore produce a greater effect.

48. Coil No. 1 remaining as before, helix No. 1, which is nine inches in diameter, was substituted for the small helix of the last experiment, and with this the effect at a distance was much increased. When coil No. 2 was added to coil No. 1, and the currents from two small batteries sent through these, shocks were distinctly perceptible through the tongue, when the dis-

tance of the planes of the coils and the three helices, united as one, was increased to thirty-six inches.

49. The action at a distance was still further increased by coiling the long wire of the large spool into the form of a ring of four feet in diameter, and placing parallel to this another ring, formed of the four ribbons of coils No. 1, 2, 3, and 4. When a current from a single battery of thirty-five feet of zinc surface was passed through the ribbon conductor, shocks through the tongue were felt when the rings were separated to the distance of four feet. As the conductors were approximated, the shocks became more and more severe; and when at the distance of twelve inches, they could not be taken through the body.

50. It may be stated in this connection, that the galvanic induction of magnetism in soft iron, in reference to distance, is also surprisingly great. A cylinder of soft iron, two inches in diameter and one foot long, placed in the centre of the ring of copper ribbon, with the battery above mentioned, becomes strongly magnetic.

51. I may, perhaps, be excused for mentioning in this communication that the induction at a distance affords the means of exhibiting some of the most astonishing experiments, in the line of *physique amusante,* to be found perhaps in the whole course of science. I will mention one which is somewhat connected with the experiments to be described in the next section, and which exhibits the action in a striking manner. This consists in causing the induction to take place through the partition wall of two rooms. For this purpose coil No. 1 is suspended against the wall in one room, while a person in the adjoining one receives the shock by grasping the handles of the helix, and approaching it to the spot opposite to which the coil is suspended. The effect is as if by magic, without a visible cause. It is best produced through a door or thin wooden partition.

52. The action at a distance affords a simple method of graduating the intensity of the shock in the case of its application to medical purposes. The helix may be suspended by a string passing over a pulley, and then gradually lowered down towards the plane of the coil, until the shocks are of the required intensity. At the request of a medical friend I have lately administered the induced current precisely in this way, in a case of paralysis of a part of the nerves of the face.

53. I may also mention that the energetic action of the spiral conductors enables us to imitate, in a very striking manner, the inductive operation of the magneto-electrical machine, by means of an uninterrupted galvanic current. For this purpose it is only necessary to arrange two coils to represent the two poles of a horseshoe magnet, and to cause two helices to revolve past them in a parallel plane. While a constant current is passing through each coil, in opposite directions, the effect of the rotation of the helices is precisely the same as that of the revolving armature in the machine.

54. A remarkable fact should here be noted in reference to helix No. 4, which is connected with a subsequent part of the investigation. This helix is formed of copper wire, the spires of which are insulated by a coating of cement instead of thread, as in the case of the others. After being used in the above experiments a small discharge from a Leyden jar was passed through it, and on applying it again to the coil I was much surprised to find that scarcely any signs of a secondary current could be obtained.

55. The discharge had destroyed the insulation in some part, but this was not sufficient to prevent the magnetizing of a bar of iron introduced into the opening at the centre. The effect appeared to be confined to the inductive action. The same accident had before happened to another coil of nearly the same kind. It was therefore noted as one of some importance. An explanation was afterwards found in a peculiar action of the secondary current.

Section 4

On the Effects Produced by Interposing Different Substances between the Conductors

56. Sir H. Davy found, in magnetizing needles by an electrical discharge, that the effect took place through interposed plates of all substances, conductors, and non-conductors.* The experiment which I have given in paragraph 51 would appear to indicate that the inductive action which produces the secondary current might also follow the same law.

* Philosophical Transactions

57. To test this the compound helix was placed about five inches above coil No. 1, Fig. 5, and a plate of sheet iron, about 1/10th of an inch thick, interposed. With this arrangement no shocks could be obtained; although, when the plate was withdrawn, they were very intense.

58. It was at first thought that this effect might be peculiar to the iron, on account of its temporary magnetism; but this idea was shown to be erroneous by substituting a plate of zinc of about the same size and thickness. With this the screening influence was exhibited as before.

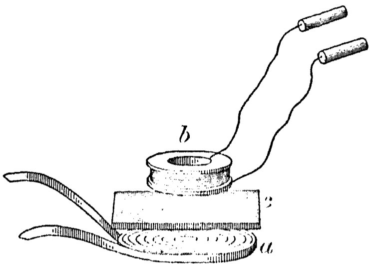

FIG. 5.—*a* represents coil No. 1, *b* helix No. 1, and *c* an interposed plate of metal.

59. After this a variety of substances was interposed in succession, namely, copper, lead, mercury, acid, water, wood, glass, etc.; and it was found that all the perfect conductors, such as the metals, produced the screening influence; but non-conductors as glass, wood, etc., appeared to have no effect whatever.

60. When the helix was separated from the coil by a distance only equal to the thickness of the plate, a slight sensation could be perceived even when the zinc of 1/10th of an inch in thickness was interposed. This effect was increased by increasing the quantity of the battery current. If the thickness of the plate was diminished, the induction through it became more intense. Thus a sheet of tinfoil interposed produced no perceptible influence; also four sheets of the same were attended with the same result. A certain thickness of metal is therefore required to produce the screening effect, and this thickness depends on the quantity of the current from the battery.

61. The idea occurred to me that the screening might, in some way, be connected with an instantaneous current in the

plate, similar to that in the induction by magnetic rotation, discovered by M. Arago. The ingenious variation of this principle by Messrs. Babbage and Herschel, furnished me with a simple method of determining this point.

62. A circular plate of lead was interposed, which caused the induction in the helix almost entirely to disappear. A slip of the metal was then cut out in the direction of a radius of the circle, as is shown in Fig. 6. With the plate in this condition, no screening was produced; the shocks were as intense as if the metal were not present.

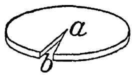

FIG. 6.—*a* represents a lead plate, of which the sector *b* is cut out.

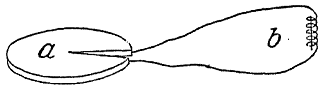

FIG. 7.—*a* represents a lead plate, *b* the magnetizing spiral.

63. This experiment, however, is not entirely satisfactory, since the action might have taken place through the opening of the lead; to obviate this objection another plate was cut in the same manner, and the two interposed with a glass plate between them, and so arranged that the opening in the one might be covered by the continuous part of the other. Still shocks were obtained with undiminished intensity.

64. But the existence of a current in the interposed conductor was rendered certain by attaching the magnetizing spiral by means of two wires to the edge of the opening in the circular plate, as is shown in Fig. 7. By this arrangement the latent current was drawn out, and its direction obtained by the polarity of a needle placed in the spiral at *b*.

65. This current was a secondary one, and its direction in conformity with the discovery of Dr. Faraday, was found to be the same as that of the primary current.

66. That the screening influence is in some way produced by the neutralizing action of the current thus obtained, will be clear from the following experiment. The plate of zinc, before mentioned, which is nearly twice the diameter of the helix, instead of being placed between the conductors, was put on the top of the helix, and in this position, although the neutralization was not as perfect as before, yet a great reduction was observed in the in-

67. But here a very interesting and puzzling question occurs. How does it happen that two currents, both in the same direction, can neutralize each other? I was at first disposed to consider the phenomenon as a case of real electrical interference, in which the impulses succeed each other by some regular interval. But if this were true the effect should depend on the length and other conditions of the current in the interposed conductor. In order to investigate this, several modifications of the experiments were instituted.

68. First a flat coil (No. 3) was interposed instead of the plates. When the two ends of this were separated, the shocks were received as if the coil were not present; but when the ends were joined, so as to form a perfect metallic circuit, no shocks could be obtained. The neutralization with the coil in this experiment was even more perfect than with the plate.

69. Again, coil No. 2, in the form of a ring, was placed not between the conductors, but around the helix. With this disposition of the apparatus, and the ends of the coil joined, the shocks were scarcely perceptible, but when the ends were separated, the presence of the coil had no effect.

70. Also when helices No. 1 and 2 were together submitted to the influence of coil No. 1, the ends of the one being joined, the other gave no shock.

71. The experiments were further varied by placing helix No. 2 within a hollow cylinder of sheet brass, and this again within coil No. 2 in a manner similar to that shown in Fig. 12, which is intended to illustrate another experiment. In this arrangement the neutralizing action was exhibited as in the case of the plate.

72. A hollow cylinder of iron was next substituted for the one of brass, and with this also no shocks could be obtained.

73. From these experiments it is evident that the neutralization takes place with currents in the interposed or adjoining conductors of all lengths and intensities, and therefore cannot, as it appears to me, be referred to the interference of two systems of vibrations.

74. This part of the investigation was, for a time, given up almost in despair, and it was not until new light had been obtained from another part of the inquiry, that any further advances could be made towards a solution of the mystery.

75. Before proceeding to the next Section I may here state that the phenomenon mentioned, paragraph 54, in reference to helix No. 4, is connected with the neutralizing action. The electrical discharge having destroyed the insulation at some point, a part of the spires would thus form a shut circuit, and the induction in this would counteract the action in the other part of the helix; or in other words, the helix was in the same condition as the two helices mentioned in paragraph 70, when the ends of the wire of one were joined.

76. Also the same principle appears to have an important bearing on the improvement of the magneto-electrical machine: since the plates of metal which sometimes form the ends of the spool containing the wire, must necessarily diminish the action, and also from experiment of paragraph 72 the armature itself may circulate a closed current which will interfere with the intensity of the induction in the surrounding wire. I am inclined to believe that the increased effect observed by Sturgeon and Calland, when a bundle of wire is substituted for a solid piece of iron, is at least in part due to the interruption of these currents. I hope to resume this part of the subject, in connection with several other points, in another communication to the Society.

77. The results given in this Section may, at first sight, be thought at variance with the statements of Sir H. Davy, that needles could be magnetized by an electrical discharge with conductors interposed. But from his method of performing the experiment, it is evident that the plate of metal was placed between a straight conductor and the needle. The arrangement was therefore similar to the interrupted circuit in the experiment with the cut plate (62), which produces no screening effect. Had the plate been curved into the form of a hollow cylinder, with the two ends in contact, and the needle placed within this, the effect would have been otherwise.

Section 5

On the Production and Properties of Induced Currents of the Third, Fourth, and Fifth Order

78. The fact of the perfect neutralization of the primary cur-

clude that if the latter could be drawn out, or separated from the influence of the former, it would itself be capable of producing a new induced current in a third conductor.

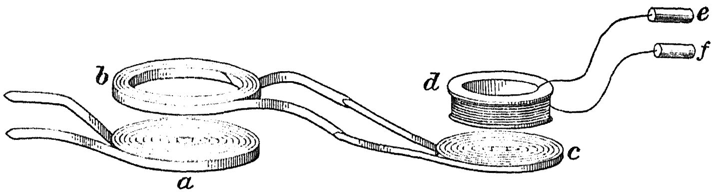

FIG. 8.—*a* coil No. 1, *b* coil No. 2, *c* coil No. 3, *d* helix No. 1.

79. The arrangement exhibited in Fig. 8 furnishes a ready means of testing this. The primary current, as usual, is passed through coil No. 1, while coil No. 2 is placed over this to receive the induction, with its ends joined to those of coil No. 3. By this disposition the secondary current passes through No. 3; and since this is at a distance, and without the influence of the primary, its separate induction will be rendered manifest by the effects on helix No. 1. When the handles *e*, *f*, are grasped, a powerful shock is received, proving the induction of a tertiary current.

80. By a similar but more extended arrangement, as shown in Fig 9, shocks were received from the currents of a fourth and fifth order; and with a more powerful primary current, and additional coils, a still greater number of successive inductions might be obtained.

81. The induction of currents of different orders, of sufficient intensity to give shocks, could scarcely have been anticipated from our previous knowledge of the subject. The secondary current consists as it were of a single wave of the natural electricity of the wire, disturbed but for an instant by the induction of the primary; yet this has the power of inducing another current, but little inferior in energy to itself, and thus produces effects apparently much greater in proportion to the quantity of electricity in motion than the primary current.

82. Some difference may be conceived to exist in the action of the induced currents, and that from the battery, since they are apparently different in nature; the one consisting, as we may

such impulses, or a continuous action. It was therefore important to investigate the properties of these currents, and to compare the results with those before obtained.

83. First, in reference to the intensity, it was found that with the small battery a shock could be given from the current of the third order to twenty-five persons joining hands; also shocks perceptible in the arms were obtained from a current of the fifth order.

84. The action at a distance was also much greater than could have been anticipated. In one experiment shocks from the tertiary current were distinctly felt through the tongue, when helix No. 1 was at the distance of eighteen inches above the coil transmitting the secondary currents.

85. The same screening effects were produced by the interposition of plates of metal between the conductors of the different orders, as those which have been described in reference to the primary and secondary currents.

86. Also when the long helix is placed over a secondary current generated in a short coil, and which is therefore, as we have before shown, one of quantity, a tertiary current of intensity is produced.

87. Again, when the intensity current of the last experiment is passed through a second helix, and another coil is placed over this, a quantity current is again produced. Therefore, in the case of these currents as in that of the primary, a *quantity current can be induced from one of intensity, and the converse.* By

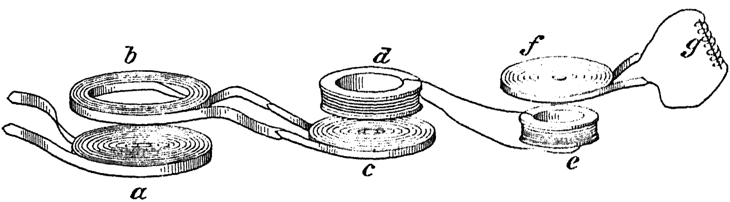

FIG. 9.—*a* coil No. 1, *b* coil No. 2, *c* coil No. 3, *d* helix No. 1, *e* helix No. 2 and 3, *f* coil No. 4, and *g* magnetizing spiral.

the arrangement of the apparatus as shown in Fig. 9, these different results are exhibited at once. The induction from coil No. 3 to helix No. 1 produces an intensity current, and

88. If the ends of coil No. 2, as in the arrangement of Fig. 8, be united to helix No. 1 instead of coil No. 3, no shocks can be obtained; the quantity current of coil No. 2 appears not to be of sufficient intensity to pass through the wire of the long helix.

89. Also, no shocks can be obtained from the handles attached to helix No. 2, in the arrangement exhibited in Fig. 10. In this

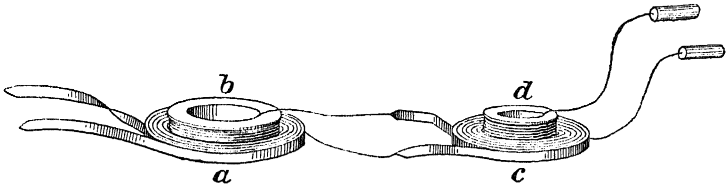

FIG. 10.—*a* coil No. 1, *b* helix No. 1, *c* coil No. 3, and *d* helix No. 3.

case the quantity of electricity in the current from the helix appears to be too small to produce any effect unless its power is multiplied by passing it through a conductor of many spires.

90. The next inquiry was in reference to the direction of these currents, and this appeared important in connection with the nature of the action. The experiments of Dr. Faraday would render it probable, that at the beginning and ending of the secondary current, its induction on an adjacent wire is in contrary directions, as is shown to be the case in the primary current. But the whole action of a secondary current is so instantaneous, that the inductive effects at the beginning and ending cannot be distinguished from each other, and we can only observe a single impulse, which, however, may be considered as the difference of two impulses in opposite directions.

91. The first experiment happened to be made with a current of the fourth order. The magnetizing spiral (11) was attached to the ends of the coil No. 4, Fig. 9, and by the polarity of the needle it was found that this current was in the same direction with the secondary and primary currents.* By a too hasty generalization, I was led to conclude, from this experiment, that the currents of all orders are in the same direction as that of the

* It should be recollected that all the inductions which have been mentioned were produced at the moment of breaking the circuit of the battery current. The induction at the formation of the current is too feeble to

battery current, and I was the more confirmed in this from the results of my first experiments on the currents of ordinary electricity. The conclusion, however, caused me much useless labor and perplexity, and was afterwards proved to be erroneous.

92. By a careful repetition of the last experiment, in reference to each current, the important fact was discovered, that *there exists an alternation in the direction of the currents of the several orders, commencing with the secondary.* This result was so extraordinary that it was thought necessary to establish it by a variety of experiments. For this purpose the direction was determined by decomposition, and also by the galvanometer, but the result was still the same; and at this stage of the inquiry I was compelled to the conclusion that the directions of the several currents were as follows:

Primary current	+
Secondary current	+
Current of the third order	—
Current of the fourth order	+
Current of the fifth order	—

93. In the first glance at the above table, we are struck with the fact that the law of alternation is complete, except between the primary and secondary currents, and it appeared that this exception might possibly be connected with the induced current which takes place in the first coil itself, and which gives rise to the phenomena of the spiral conductor. If this should be found to be *minus* we might consider it as existing between the primary and secondary, and the anomaly would thus disappear. Arrangements were therefore made to fully satisfy myself on this point. For this purpose the decomposition of dilute acid and the use of the galvanometer were resorted to, by placing the apparatus between the ends of a cross wire attached to the extremities of the coil, as in the arrangement described by Dr. Faraday (ninth series); but all the results persisted in giving a direction to this current the same as stated by Dr. Faraday, namely, that of the primary current. I was, therefore, obliged to abandon the supposition that the anomaly in the change of the current is connected with the induction of the battery current on itself.

94. Whatever may be the nature or causes of these changes in the direction, they offer a ready explanation of the neutralizing

action of the plate interposed between two conductors, since a secondary current is induced in the plate; and although the action of this as has been shown, is in the same direction as the current from the battery, yet it tends to induce a current in the adjacent conducting matter of a contrary direction. The same explanation is also applicable to all the other cases of neutralization, even to those which take place between the conductors of the several orders of currents.

95. The same principle explains some effects noted in reference to the induction of a current on itself. If a flat coil be connected with the battery, of course sparks will be produced by the induction, at each rupture of the circuit. But if in this condition, another flat coil, with its ends joined, be placed on the first coil, the intensity of the shock is much diminished, and when the several spires of the two coils are mutually interposed by winding the two ribbons together into one coil, the sparks entirely disappear in the coil transmitting the battery current, when the ends of the other are joined. To understand this, it is only necessary to mention that the induced current in the first coil is a true secondary current, and it is therefore neutralized by the action of the secondary in the adjoining conductor; since this tends to produce a current in the opposite direction.

96. It would also appear from the perfect neutralization which ensues in the arrangement just before described, that the induced current in the adjoining conductor is more powerful than that of the first conductor; and we can easily see how this may be. The two ends of the second coil are joined, and it thus forms a perfect metallic circuit; while the circuit of the other coil may be considered as partially interrupted, since to render the spark visible the electricity must be projected as it were through a small distance of air.

97. We would also infer that two contiguous secondary currents, produced by the same induction, would partially counteract each other. Moving in the same direction they would each tend to induce a current in the other of an opposite direction. This is illustrated by the following experiment: helix No. 1 and 2 were placed together, but not united, above coil No. 1, so that they each might receive the induction; the larger was then gradually removed to a greater distance from the coil, until the intensity of the shock from each was about the same. When the

ends of the two were united, so that the shock would pass through the body from the two together, the effect was apparently less than with one helix alone. The result, however, was not as satisfactory as in the case of the other experiments; a slight difference in the intensity of two shocks could not be appreciated with perfect certainty.

Section 6

The Production of Induced Currents of the Different Orders from Ordinary Electricity

98. Dr. Faraday, in the ninth series of his researches, remarks that "the effect produced at the commencement and the end of a current (which are separated by an interval of time when that current is supplied from a voltaic apparatus) must occur at the same moment when a common electrical discharge is passed through a long wire. Whether if it happen accurately at the same moment they would entirely neutralize each other, or whether they would not still give some definite peculiarity to the discharge, is a matter remaining to be examined."

99. The discovery of the fact that the secondary current, which exists but for a moment, could induce another current of considerable energy, gave some indication that similar effects might be produced by a discharge of ordinary electricity, provided a sufficiently perfect insulation could be obtained.

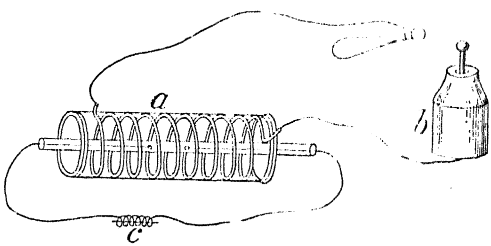

FIG. 11.—*a* glass cylinder, *b* Leyden jar, *c* magnetizing spiral.

100. To test this a hollow glass cylinder, Fig. 11, of about six inches in diameter, was prepared with a narrow ribbon of tinfoil,

about thirty feet long, pasted spirally around the outside and a similar ribbon of the same length, pasted on the inside; so that the corresponding spires of the two were directly opposite each other. The ends of the inner spiral passed out of the cylinder through a glass tube, to prevent all direct communication between the two. When the ends of the inner ribbon were joined by the magnetizing spiral (11), containing a needle, and a discharge from a half gallon jar sent through the outer ribbon, the needle was strongly magnetized in such a manner as to indicate *an induced current through the inner ribbon in the same direction as that of the current of the jar.* This experiment was repeated many times, and always with the same result.

101. When the ends of one of the ribbons were placed very nearly in contact, a small spark was perceived at the opening, the moment the discharge took place through the other ribbon.

102. When the ends of the same ribbon were separated to a considerable distance, a larger spark than the last could be drawn from each end by presenting a ball, or the knuckle.

103. Also if the ends of the outer ribbon were united, so as to form a perfect metallic circuit, a spark could be drawn from any point of the same, when a discharge was sent through the inner ribbon.

104. The sparks in the two last experiments are evidently due to the action known in ordinary electricity by the name of the lateral discharge. To render this clear, it is perhaps necessary to recall the well known fact, that when the knob of a jar is electrified positively, and the outer coating is connected with the earth, then the jar contains a small excess of positive electricity beyond what is necessary to perfectly neutralize the negative surface. If the knob be put in communication with the earth, the extra quantity, or the free electricity, as it is sometimes called, will be on the negative side. When the discharge took place in the above experiments, the inner ribbon became for an instant charged with this free electricity, and consequently threw off from the outer ribbon, by ordinary induction, the sparks described. It therefore became a question of importance to determine whether the induced current described in paragraph 100 was not also a result of the lateral discharge, instead of being a true case of a secondary current analogous to those produced from galvanism. For this purpose the jar was charged, first

with the outer coating in connection with the earth, and again with the knob in connection with the same, so that the extra quantity might be in the one case *plus* and in the other *minus;* but the direction of the induced current was not affected by these changes; it was always the same, namely, from the positive to the negative side of the jar.

105. When, however, the quantity of free electricity was increased, by connecting the knob of the jar with a globe about a foot in diameter, the intensity of the magnetism appeared to be somewhat diminished, if the extra quantity was on the negative side; and this might be expected, since the free electricity, in its escape to the earth through the ribbon, in this case would tend to induce a feeble current in the opposite direction to that of the jar.

106. The spark from an insulated conductor may be considered as consisting almost entirely of this free or extra electricity, and it was found that this was also capable of producing an induced current, precisely the same as that from the jar. In the experiment which gave this result, one end of the outer ribbon of the cylinder (100) was connected with the earth, and the other caused to receive a spark from a conductor fourteen feet long, and nearly a foot in diameter. The direction of the induced current was the same as that of the spark from the conductor.

107. From these experiments it appears evident that the discharge from a Leyden jar possesses the property of inducing a secondary current precisely the same as the galvanic apparatus, and also that this induction is only so far connected with the phenomenon of the lateral discharge as this latter partakes of the nature of an ordinary electrical current.

108. Experiments were next made in reference to the production of currents of the different orders by ordinary electricity. For this purpose a second cylinder was prepared with ribbons of tinfoil, in a similar manner to the one before described. The two were then so connected that the secondary current from the first would circulate around the second. When a discharge was passed through the outer ribbon of the first cylinder, a tertiary current was induced in the inner ribbon of the second. This was rendered manifest by the magnetizing of a needle in

109. Also by the addition, in the same way, of a third cylinder, a current of the fourth order was developed. The same result was likewise obtained by using the arrangement of the coils and helices shown in Fig. 9. For these experiments, however, the coils were furnished with a double coating of silk, and the contiguous conductors separated by a large plate of glass.

110. Screening effects, precisely the same as those exhibited in the action of galvanism, were produced by interposing a plate of metal between the conductors of different orders, Figures 8 and 9. The precaution was taken to place the plate between two frames of glass, in order to be assured that the effect was not due to a want of perfect insulation.

111. Also analogous results were found when the experiments were made with coils interposed instead of plates, as described in paragraph 68. When the ends of the interposed coils were separated, no screening was observed, but when joined the effect was produced. The existence of the induced current in all these experiments, was determined by the magnetism of a needle in a spiral attached to one of the coils.

112. Likewise shocks were obtained from the secondary current by an arrangement shown in Fig. 12. Helices No. 2 and

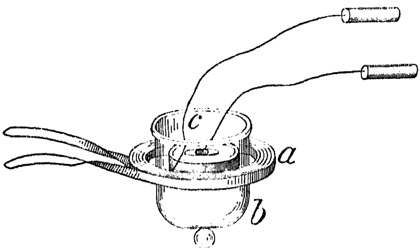

FIG. 12.—*a* coil No. 2, *b* an inverted bell glass, *c* helices Nos. 2 and 3.

No. 3 united are put within a glass jar, and coil No. 2 is placed around the same. When the handles are grasped a shock is felt at the moment of the discharge, through the outer coil. The shocks, however, were very different in intensity with different discharges from the jar. In some cases no shock was received, when again, with a less charge, a severe one was obtained. But these irregularities find an explanation in a subsequent part of the investigation.

113. In all these experiments, the results with ordinary and galvanic electricity are similar. But at this stage of the investigation there appeared what was at first considered a remarkable difference in the action of the two. I allude to the direction of the currents of the different orders. These, in the experiments with the glass cylinders, instead of exhibiting the alternations of the galvanic currents (92), were all in the same direction as the discharge from the jar, or in other words, they were all *plus*.

114. To discover, if possible, the cause of this difference, a series of experiments was instituted; but the first fact developed, instead of affording any new light, seemed to render the obscurity more profound. When the directions of the currents were taken in the arrangement of the coils (Fig. 9) the discrepancy vanished. *Alternations were found the same as in the case of galvanism.* This result was so extraordinary that the experiments were many times repeated, first with the glass cylinders and then with the coils; the results, however, were always the same. The cylinders gave currents all in one direction; the coils in alternate directions.

115. After various hypotheses had been formed, and in succession disproved by experiment, the idea occurred to me that the direction of the currents might depend on the distance of the conductors, and this appeared to be the only difference existing in the arrangement of the experiments with the coils and the cylinders.* In the former the distance between the ribbons was nearly one inch and a half, while in the latter it was only the thickness of the glass, or about 1/20th of an inch.

116. In order to test this idea, two narrow slips of tinfoil, about twelve feet long, were stretched parallel to each other, and separated by thin plates of mica to the distance of about 1/50th of an inch. When a discharge from the half gallon jar was passed through one of these, an induced current in the same direction was obtained from the other. The ribbons were then separated, by plates of glass, to the distance of 1/20th of an inch; the current was still in the same direction, or *plus*. When

* This idea was not immediately adopted, because I had previously experimented on the direction of the secondary current from galvanism

the distance was increased to about 1/8th of an inch, no induced current could be obtained; and when they were still further separated the current again appeared, but was now *found to have a different direction, or to be minus.* No other change was observed in the direction of the current; the intensity of the induction decreased as the ribbons were separated. The existence and direction of the current, in this experiment, were determined by the polarity of the needle in the spiral attached to the ends of one of the ribbons.

117. The question at this time arose, whether the direction of the current, as indicated by the polarity of the needle, was the true one, since the magnetizing spiral might itself, in some cases induce an opposite current. To satisfy myself on this point a series of charges, of various intensity and quantity, from a single spark of the large conductor to the full charge of nine jars, were passed through the small spiral, which had been used in all the experiments, but they all gave the same polarity. The interior of this spiral is so small, that the needle is throughout in contact with the wire.

118. The fact of a change in the direction of the induced current by a change in the distance of the conductors, being thus established, a great number and variety of experiments were made to determine the other conditions on which the change depends. These were sought for in a variation of the intensity and quantity of the primary discharge, in the length and thickness of the wire, and in the form of the circuit. The results were, however, in many cases anomalous, and are not sufficiently definite to be placed in detail before the Society. I hope to resume the investigation at another time, and will therefore at present briefly state only those general facts which appear well established.

119. With a single half gallon jar, and the conductors separated to a distance less than 1/20th of an inch, the induced current is always in the same direction as the primary. But when the conductors are gradually separated, there is always found a distance at which the current begins to change its direction. This distance depends certainly on the amount of the discharge, and probably on the intensity, and also on the length and thickness of the conductors. With a battery of eight half gallon jars, and parallel wires of about ten feet long, the

change in the direction did not take place at a less distance than from twelve to fifteen inches, and with a still larger battery and longer conductors, no change was found, although the induction was produced at the distance of several feet.

120. The facts given in the last paragraph relate to the inductive action of the primary current; but it appears from the results detailed in paragraphs 110 and 114, that the currents of all the other orders also change the direction of the inductive influence with a change of the distance. In these cases, however, the change always takes place at a very small distance from the conducting wire; and in this respect the result is similar to the effect of a *primary current* from the discharge of a small jar.

121. The most important experiments, in reference to distance, were made in the lecture room of my respected friend Dr. Hare, of Philadelphia, with the splendid electrical apparatus described in the Fifth Volume (new series) of the Transactions of this Society. The battery consists of thirty-two jars, each of the capacity of a gallon. A thick copper wire of about 1/10th of an inch in diameter and eighty feet in length, was stretched across the lecture room, and its ends brought to the battery, so as to form a trapezium, the longer side of which was about thirty-five feet. Along this side a wire was stretched of the ordinary bell size, and the extreme ends of this joined by a spiral, similar to the arrangement shown in Fig. 13. The

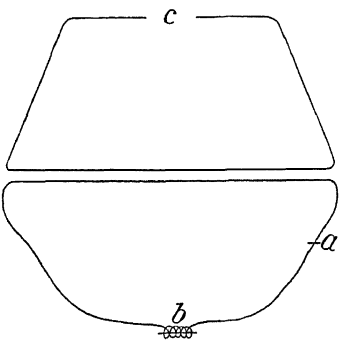

FIG. 13.—*c* place of the battery spiral.

two wires were at first placed within the distance of about an inch, and afterwards constantly separated after each discharge of the whole battery through the thick wire. When a break was made in the second wire at *a*, no magnetism was developed in a needle in the spiral at *b*, but when the circuit was complete, the needle at each discharge indicated a current in the same direction as that of the battery. When the distance of the two

wire placed in two glasses of mercury, and a finger of each hand plunged into the metal, a shock was received. The direction of the current was still the same, but the magnetism not as strong as at a less distance.

122. The second wire was next arranged around the other, so as to enclose it. The magnetism by this arrangement appeared stronger than with the last; the direction of the current was still the same, and continued thus, until the two wires were at every point separated to the distance of twelve feet, except in one place where they were obliged to be crossed at the distance of seven feet, but here the wires were made to form a right angle with each other, and the effect of the approximation was therefore (46) considered as nothing. The needle at this surprising distance was tolerably strongly magnetized, as was shown by the quantity of filings which would adhere to it. The direction of the current was still the same as that of the battery. The form of the room did not permit the two wires to be separated to a greater distance. The whole length of the circuit of the interior large wire was about eighty feet; that of the exterior one hundred and twenty. The two were not in the same plane and a part of the outer passed through a small adjoining room.

123. The results exhibited in this experiment are such as could scarcely have been anticipated by our previous knowledge of the electrical discharge. They evince a remarkable inductive energy, which has not before been distinctly recognized, but which must form an important part in the discharge of electricity from the clouds. Some effects which have been observed during thunder storms, appear to be due to an action of this kind.

124. Since a discharge of ordinary electricity produces a secondary current in an adjoining wire, it should also produce an analogous effect in its own wire; and to this cause may be now referred the peculiar action of a long conductor. It is well known that the spark from a very long wire, although quite short, is remarkable pungent. I was so fortunate as to witness a very interesting exhibition of this action during some experiments on atmospheric electricity made by a committee of the Franklin Institute, in 1836. Two kites were attached, one above the other, and raised with a small iron wire in place of a string. On the occasion at which I was present, the wire

was extended by the kites to the length of about one mile. The day was perfectly clear, yet the sparks from the wire had so much projectile force (to use a convenient expression of Dr. Hare) that fifteen persons joining hands and standing on the ground, received the shock at once, when the first person of the series touched the wire. A Leyden jar being grasped in the hand by the outer coating, and the knob presented to the wire, a severe shock was received, as if by a perforation of the glass, but which was found to be the result of the sudden and intense induction.

125. These effects were evidently not due to the accumulated intensity at the extremities of the wire, on the principles of ordinary electrical distribution, since the knuckle required to be brought within about a quarter of an inch before the spark could be received. It was not alone the quantity, since the experiments of Wilson prove that the same effect is not produced with an equal amount of electricity on the surface of a large conductor. It appears evidently therefore a case of the induction of an electrical current on itself. The wire is charged with a considerable quantity of feeble electricity, which passes off in the form of a current along its whole length, and thus the induction takes place at the end of the discharge, as in the case of a long wire transmitting a current of galvanism.

126. It is well known that the discharge from an electrical battery possesses great divellent powers; that it entirely separates, in many instances, the particles of the body through which it passes. This force acts in part, at least, in the direction of the line of the discharge, and appears to be analogous to the repulsive action discovered by Ampère, in the consecutive parts of the same galvanic current. To illustrate this, paste on a piece of glass a narrow slip of tinfoil, cut it through at several points, and loosen the ends from the glass at the places so cut. Pass a discharge through the tinfoil from about nine half gallon jars; the ends, at each separation, will be thrown up, and sometimes bent entirely back, as if by the action of a strong repulsive force between them. This will be understood by a reference to Fig. 14; the ends are shown bent back

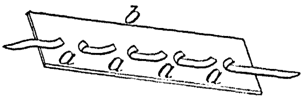

FIG. 14.—*b* glass plate; *a*, *a*, *a*, *a*, openings in tinfoil.

at *a, a, a, a.* In the popular experiment of the pierced card, the bur on each side appears to be due to an action of the same kind.

127. It now appears probable from the facts given in paragraphs 119 and 120, that the table in paragraph 92 is only an approximation to the truth, and that each current from galvanism as well as from electricity, first produces an inductive action in the direction of itself, and that the inverse influence takes place at a little distance from the wire.

128. To test this the compound helix was placed on coil No. 1, to receive the induction, and its ends joined to those of the outer ribbon of tinfoil of the glass cylinder, while the magnetizing spiral was attached to the ends of the inner riband. A feeble tertiary current was produced by this arrangement, which in two cases gave a polarity to the needle indicating a direction the same as that of the primary current. In other cases the magnetism was either imperceptible or *minus*. With an arrangement of two coils of wires around two glass cylinders, one within the other, the same effect was produced. The magnetism was less when the distance of the two sets of spires was smaller, indicating, as it would appear, an approximation to a position of neutrality. These results are rather of a negative kind, yet they appear to indicate the same change with distance in the case of the galvanic currents as in that of the discharge of ordinary electricity. The distance, however, at which the change takes place would seem to be less in the former than in the latter.

129. There is a perfect analogy between the inductive action of the primary current from the galvanic apparatus and of that from the larger electrical battery. The point of change, in each, appears to be at a great distance.

130. The neutralizing effect described in Section 4 may now be more definitely explained by saying that when a third conductor is acted on at the same time by a primary and secondary current (unless it be very near the second wire) it will fall into the region of the *plus* influence of the former, and into that of the *minus* influence of the latter; and hence no induction will be produced.

131. This will be rendered perfectly clear by Fig. 15, in which *a* represents the conductor of the primary current, *b* that of

the secondary, and *c* the third conductor. The characters + + +, etc., beginning at the middle of the first conductor and extending downwards, represent the constant *plus* influence of the primary current, and those + 0 — —, etc., beginning at the second conductor. indicate its inductive influence as chang-

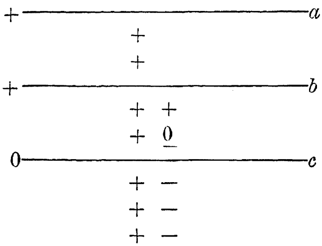

FIG. 15.

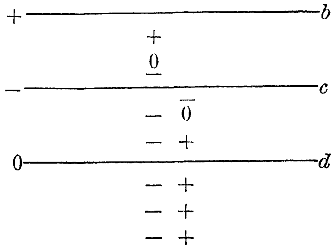

FIG. 16.

ing with the distance. The third conductor, as is shown by the figure, falls in the *plus* region of the primary current, and in the *minus* region of the secondary, and hence the two actions neutralize each other, and no apparent result is produced.

132. Fig. 16 indicates the method in which the neutralizing effect is produced in the case of the secondary and tertiary currents. The wire conducting the secondary current is represented by *b*, that conducting the tertiary by *c*, and the other wire, to receive the induction of these, by *d*. The direction of the influence, as before, is indicated by + 0 — —, etc., and the third wire is again seen to be in the *plus* region of the one current, and in the *minus* of the other. If, however, *d* is placed sufficiently near *c*, then neutralization will not take place, but the two currents will conspire to produce in it an induction in the same direction. A similar effect would also be produced were the wire *c*, in Fig. 15, placed sufficiently near the conductor *b*.

133. Currents of the several orders were likewise produced from the excitation of the magneto-electrical machine. The same neutralizing effects were observed between these as in the case of the currents from the galvanic battery, and hence we may infer that also the same alternations take place in the direction of the several currents.

134. In conclusion, I may perhaps be allowed to state, that the facts here presented have been deduced from a laborious series of experiments, and are considered as forming some addition to our knowledge of electricity, independently of any theoretical considerations. They appear to be intimately connected with various phenomena, which have been known for some years, but which have not been referred to any general law of action. Of this class are the discoveries of Savary on the alternate magnetism of steel needles placed at different distances from the line of a discharge of ordinary electricity,* and also the magnetic, screening influence of all metals, discovered by Dr. Snow Harris, of Plymouth.† A comparative study of the phenomena observed by these distinguished *savants,* and those given in this paper, would probably lead to some new and important developments. Indeed every part of the subject of electro-dynamic induction appears to open a field for discovery, which experimental industry cannot fail to cultivate with immediate success.

Note

On the evening of the meeting at which my investigations were presented to the Society, my friend, Dr. Bache, of the Girard College, gave an account of the investigations of Professor Ettingshausen, of Vienna, in reference to the improvement of the magneto-electric machine, some of the results of which he had witnessed at the University of Vienna, about a year since. No published account of these experiments has yet reached this country, but it appears that Professor Ettingshausen had been led to suspect the development of a current in the metal of the keeper of the magneto-electric machine, which diminished the effect of the current in the coil about the keeper, and hence to separate the coil from the keeper by a ring of wood of some thickness, and afterwards, to prevent entirely the circulation of currents in the keeper, by dividing it into segments, and separating them by a non-conducting material. I am not aware of the result of this last device, nor whether the

* *Annales de Chimie et de Physique,* 1827.

† *Philosophical Transactions,* 1831.

mechanical difficulties in its execution were fully overcome. It gives me pleasure to learn that the improvements, which I have merely suggested as deductions from the principles of the interference of induced currents (76), should be in accordance with the experimental conclusions of the above named philosopher.*

* Reprinted in Silliman's *American Journal of Science,* March, 1840, Vol. XXXVIII, pp. 209–243.

On Electro-Dynamic Induction
(*Continued*)

CONTENTS

Contributions to Electricity and Magnetism

No. IV

On Electro-Dynamic Induction (*continued*)

By JOSEPH HENRY

(*Transactions American Philosophical Society*, n. s., Vol. VIII, pp. 1-35, read June 19, 1840; *Scientific Writings*, Vol. I, p. 149.)

Introduction

1. In the course of my last paper (No. III), it was stated that the investigations which it detailed were not as complete in some parts as I could wish, and that I hoped to develop them more fully in another communication. After considerable delay, occasioned by alterations in the rooms of the physical department of the college, I was enabled to resume my researches; and since then I have been so fortunate as to discover a series of new facts belonging to different parts of the general subject of my contributions. These I have announced to the Society at different times, as they were discovered, and I now purpose to select from the whole such portions as relate particularly to the principal subject of my last paper, namely, the induction at the beginning and ending of a galvanic current, and to present them as a continuation, and in a measure as the completion of this part of my researches. The other results of my labors in this line will be arranged for publication as soon as my duties will permit me to give them a more careful examination.

2. In the course of the experiments I am about to describe, I have had occasion to repeat and vary those given in my last paper, and I am happy to be able to state, in reference to the results, that except in some minor particulars which will be mentioned in the course of this paper, I have found no cause to desire a change in the accounts before published. My views, however, of the connection of the phenomena have been considerably modi-

fied, and I think rendered much more definite by the additional light which the new facts have afforded.

3. The principal articles of apparatus used in these experiments are nearly the same as those described in my last paper, namely, several flat coils, and a number of long wire helices. (No. III, 6, 7, 8.*) I have, however, added to these a constant battery, on Prof. Daniell's plan, the performance of which has fully answered my expectations, and confirmed the accounts given of this form of the instrument by its author. It consists of thirty elements, formed of as many copper cylinders, open at the bottom, each five inches and a half in height, three inches and a half in diameter, and placed in earthen cups. A zinc rod is suspended in each of these, of the same length as the cylinders, and about one inch in diameter. The several elements are connected by a thick copper wire, soldered to the copper of one element, and dipping into a cup of mercury on the zinc of the next. The copper and zinc as usual are separated by a membrane, on both sides of which is placed a solution of one part of sulphuric acid in ten parts of water; and to this is added on the side next the copper, as much sulphate of copper as will saturate the solution. The battery was sometimes used as a single series, with all its elements placed consecutively, and at others in two or three series, arranged collaterally, so as to vary the quantity and intensity of the electricity, as the occasion might require.

4. The galvanometers mentioned in this paper, and referred to in the last, are of two kinds; one, which is used with a helix, to indicate the action of an induced current of intensity, consists of about five hundred turns of fine copper wire, covered with cotton thread, and more effectually insulated by steeping the instrument in melted cement, which was drawn into the spaces between the spires by capillary attraction. The other galvanometer is formed of about forty turns of a shorter and thicker wire, and is always used to indicate an induced current, of considerable quantity, but of feeble intensity. The needle of both these instruments is suspended by a single fibre of raw silk.

5. I should also state, that in all cases where a magnetizing spiral is mentioned in connection with a helix, the article is

* The numerals II or III included in the parenthesis refer to the cor-

formed of a long, fine wire, making about one hundred turns around the axis of a hollow piece of straw about two inches and a half long: also the spiral mentioned in connection with a coil, is formed of a short wire which makes about twenty turns around a similar piece of straw. The reason of the use of the two instruments in these two cases is the same as that for the galvanometers, under similar circumstances, namely, the helix gives a current of intensity, but of small quantity, while the coil produces one of considerable quantity, but of feeble intensity.

Section 1

On the Induction Produced at the Moment of the Beginning of a Galvanic Current, etc.

6. It will be recollected that the arrangement of apparatus employed in my last series of experiments gave a powerful induction at the moment of breaking the galvanic circuit, but the effect of making the same was so feeble as scarcely to be perceptible. I was unable in any case to get indications of currents of the third or fourth orders from the beginning induction, and its action was therefore supposed to be so feeble as not materially to affect the results obtained.

7. Subsequent reflection, however, led me to conclude that in order to complete this part of my investigations, a more careful study of the induction at the beginning of the current would be desirable; and, accordingly, on resuming the experiments, my attention was first directed to the discovery of some means by which the intensity of this induction might be increased. After some preliminary experiments, it appeared probable that the desired result could be obtained by using a compound galvanic battery, instead of the single one before employed. In reference to this conjecture, the constant battery before mentioned (3) was constructed, and a series of experiments instituted with it, the results of which agreed with my anticipation.

8. In the first experiment, coil No. 2, which it will be remembered (No. III, 7) consists of a copper ribbon about sixty feet long, coiled on itself like the mainspring of a watch, was con-

copper wire, was placed on the coil to receive the induction, as is shown in Fig. 3, which is again inserted here for the convenience of the reader. This arrangement being made, currents of increasing intensity were passed through the coil by constantly retaining one of its ends in the cup of mercury forming one ex-

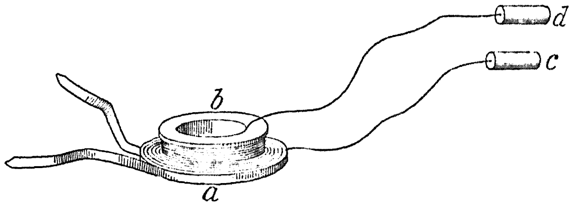

Fig. 3 (dupl.). — *a* represents coil No. 1, *b* helix No. 1, and *c*, *d*, handles for receiving the shock.

tremity of the battery, and successively plunging the other end into the cups which served to form the connections of the several elements of the battery. With the current from one element, the shock at breaking the circuit was quite severe; but at making the same it was very feeble, and could be perceived in the fingers only, or through the tongue. With two elements in the circuit, the shock at the beginning was slightly increased; with three elements the increase was more decided, while the shock at breaking the circuit remained nearly of the same intensity as at first, or was comparatively but little increased. When the number of elements was increased to *ten*, the shock at making contact was found fully equal to that at breaking, and by employing a still greater number, the former was decidedly stronger than the latter, the difference continually increasing until all the thirty elements were introduced into the circuit.

9. In my last paper, a few experiments are mentioned as being made with a compound battery of Cruickshank's construction; but from the smallness of its plates, and the rapidity with which its power declined, I was led into the error of supposing that the induction at the ending of the current, in the case of a short coil, was diminished by increasing the intensity of the battery (see paragraph 19 of No. III); but by employing the more perfect instrument of Professor Daniell in the arrangement of the last experiment, I am enabled to correct this error, and to state that the induction at the ending remains nearly the same, when the

intensity of the battery is increased. If the induction depends in any degree on the quantity of current electricity in the conductor, then a slight increase in the induction should take place, since according to theory the current is somewhat increased in quantity, in the case of a long coil, by the increase of the intensity of the battery. Although very little, if any, difference could be observed in the intensity of the shock from the secondary current, yet the snap and deflagration of the mercury appeared to be greater from the primary current, when *ten* elements of the battery were included in the circuit, than with a single one. The other results which are mentioned in my last paper in reference to the compound battery are, I believe, correctly given.

10. The intensities of the different shocks in the foregoing experiments were compared by gradually raising the helix from the coil (see Fig. 3) until on account of the distance of the conductors, the shock in one case would be so much reduced as to be scarcely perceptible through the fingers or the tongue, while the shock from another arrangement, but with the same distance of the conductors, would be evident perhaps in the hands. The same method was generally employed in the experiments in which shocks are mentioned as being compared, in the other parts of this paper.

11. Experiments were next made to determine the influence of a variation in the length of the coil, the intensity of the battery remaining the same. For this purpose the battery consisting of a single element, and the arrangement of the apparatus as represented in Fig. 3, the coil was diminished in length from sixty feet to forty-five, then to thirty, and so on. With the first mentioned length, the shock, at making contact with the battery, was of course very feeble, and could be felt only in the tongue; with the next shorter length it was more perceptible, and increased in intensity with each diminution of the coil, until a length of about fifteen feet appeared to give a maximum result.

12. The diminution of the intensity of the shock in the last experiment, after the length of the coil was diminished below fifteen feet, was due to the diminution of the number of spires of the coil, each of which, by acting on the helix, tends to increase the intensity of the secondary current, unless the combined length of the whole is too great for the intensity of the battery. That this is the fact is shown by the following experiment: the

helix was placed on a single spire or turn of the coil, and the length of the other part of the copper ribbon, which did not act on the helix, was continually shortened, until the whole of it was excluded from the circuit; in this case the intensity of the shock at the beginning was constantly increased. We may, therefore, state generally that at the beginning of the battery current, the induction of a unit of its length is increased by every diminution of the length of the conductor.

13. In the experiment given in paragraph 11, the intensity of the shock at the *ending* of the battery current diminishes with each diminution of the length of the coil; and this is also due to the decrease of the number of the spires of the coil, as is evident from an experiment similar to the last, in which a helix was placed on a coil consisting of only two turns or spires of copper from an experiment similar to the last, in which the helix was comparatively feeble, but could be felt in the hands. Different lengths of coil No. 2 were now introduced into the same circuit, but not so as to act on the helix; but although these were varied from four or five feet to the whole length of the coil (sixty feet), not the least difference in the intensity of the shock could be perceived. We have therefore the remarkable result, that the intensity of the ending induction of each unit of length of the battery current is not materially altered, at least within certain limits, by changing the length of the whole conductor. From this we would infer that the shock depends more on the intensity of the action than on the quantity of the current, since we know that the latter is diminished in a given unit of the conductor by increasing the length of the whole.

14. We have seen (8) that with a circuit composed of ten elements of the compound battery and the coil No. 2, the shock, at the beginning of the current, was fully equal to that at the ending. It was, however, found that if in this case the length of the coil was increased, this shock was diminished; and we may state as an inference from several experiments that, however great may be the intensity of the electricity from the battery, the shock at the beginning may be so reduced, by a sufficient increase of the length of the primary circuit, as to be scarcely perceptible.

15. It was also found that when the thickness of the coil was

same, the shock at the beginning of the battery current was somewhat increased. This result was produced by using a double coil; the electricity was made to pass through one strand, and immediately afterwards through both; the shock from the helix in the latter case was apparently the greater.

16. By the foregoing results we are evidently furnished with two methods of increasing at pleasure the intensity of the induction at the beginning of a battery current; — the one consisting in increasing the intensity of the source of the electricity, and the other in diminishing the resistance to conduction of the circuit while the intensity remains the same.

17. The explanation of the effects which we have given, relative to the induction at the beginning, is apparently not difficult. The resistance to conduction in the case of a long conductor and a battery of a single element is so great that the full development of the primary current may be supposed not to take place with sufficient rapidity to produce the instantaneous action on which the shock from the secondary current would seem to depend. But when a battery of a number of elements is employed, the poles of this, previous to the moment of completing the circuit, are in a state of electrical tension; and, therefore, the discharge through the conductor may be supposed to be more sudden, and hence an induction of more intensity is produced.

18. That the shock at both making and breaking the circuit in some way depends on the rapidity of formation and diminution of the current is shown by the following experiment, in which the tension just mentioned does not take place, and in which also the current appears to diminish more slowly. The two ends of the coil were placed in the two cups which formed the poles of the battery, and permanently retained there during the experiment; also at the distance of about six inches from, say, the right end of the coil, a loop was made in the ribbon, which could be plunged into the cup containing the left hand end. With this arrangement, and while only the two extreme ends of the coil were in connection with the cups of mercury, of course the current passed through the entire length of the ribbon of the coil; but by plunging the loop into the left hand cup, the whole length of the coil, except the six inches before mentioned,

loop was lifted out of the cup, the whole length was included. In this way the current in the coil could be suddenly formed and interrupted, while the poles of the battery were continually joined by a conductor, but no shock with either a single or compound battery could be obtained by this method of operation.

19. The feebleness of the shock at the beginning of the current, with a single battery and a long coil, is not entirely owing to the cause we have stated (17), namely the resistance to conduction offered by the long conductor, but also depends in a considerable degree (if not principally) on the adverse influence of the secondary current, induced in the primary conductor itself, as is shown by the result of the following experiment. Helix No. 1 was placed on a coil consisting of only three spires or turns of copper ribbon; with this the shock at both making and breaking the circuit with a single battery could be felt in the hands. A compound coil was then formed of the copper ribbons of coils No. 3 and 4 rolled together so that the several spires of the two alternated with each other, and when this was introduced into the circuit so as not to act on the helix by its induction, and the battery current passed through (for example) coil No. 3, the shock at making contact with the pole of the battery was so much reduced as to be imperceptible in the hands, while the shock at breaking the contact was about the same as before this addition was made to the length of the circuit. The ends of coil No. 4 were now joined so as to produce a closed circuit, the induced current in which would neutralize the secondary current in the battery conductor itself; and now the shock at making the contact was nearly as powerful as in the case where the short conductor alone formed the circuit with the battery. Hence the principal cause of the feebleness of the effect at the beginning of the battery current is the adverse action on the helix of the secondary current produced in the conductor of the battery circuit itself. The shock at the breaking of the circuit in this experiment did not appear affected by joining or separating the ends of coil No. 4.

20. Having investigated the conditions on which the inductive action at the beginning of a battery current depends, experiments were next instituted to determine the nature of the effects produced by this induction; and first, the coils were arranged

ducing currents of the different orders. The result with this arrangement was similar to that which I have described in reference to the ending induction, namely, currents of the third, fourth, and fifth orders were readily obtained.

21. Also, when an arrangement of apparatus was made similar to that described in paragraph 87 of my last paper, it was found that a current of intensity could be induced from one of quantity and the converse.

22. Likewise, the same screening or rather neutralizing effect was produced when a plate of metal was interposed between two consecutive conductors of the series of currents as was described (No. III, section 4) in reference to the ending induction. In short, the series of induced currents produced at the beginning of the primary current appeared to possess all the properties belonging to those of the induction at the ending of the same current.

23. I may mention in this place that I have found in the course of these experiments that the neutralizing power of a plate of metal depends in some measure on its superficial extent. Thus a broad plate which extends in every direction beyond the helix and coil, produces a more perfect screening than one of the same metal and of the same thickness, but of a diameter only a little greater than that of the coil.

24. The next step in the investigation was to determine the direction of the currents of the different orders produced by the beginning induction; and for this purpose the magnetizing spirals (5) were used, and the results obtained by these verified by the indications of the galvanometer. It should be stated here as a fact, which was afterwards found of some importance, that although the needle of the galvanometer was powerfully deflected when the instrument was placed in the circuit of the secondary current, yet a very feeble effect was produced on it by the action of a current of the third, fourth, or fifth order. The directions, however, of these currents, as indicated by the feeble motions of the needle, were the same as those given by the magnetizing spiral.

25. The direction of the different currents produced at the making of the battery current, as determined by these instruments, is as follows, namely: the direction of the secondary

mary current, and also the direction of each succeeding current is opposite to that of the one which produced it. We have, therefore, from these results, and those formerly obtained (No. III, 92), the following series of directions of currents, one produced at the moment of beginning, and the other at that of ending of the battery current.

	At the Beginning	*At the Ending*
Primary current	+	+
Secondary current	—	+
Current of the third order	+	—
Current of the fourth order	—	+
Current of the fifth order	+	—

26. These two series, at first sight may appear very different, but with a little attention they will be seen to be of the same nature. If we allow that the induction at the ending of a galvanic battery should be opposite to that at the beginning of the same, then the sign at the top of the second column may be called minus instead of plus, and we shall have the second series — + — + alternating precisely like the first.

27. In connection with the results given in the last two paragraphs, it is due to Mr. Sturgeon that I should state, that in a letter addressed to me and published in the *Annals of Electricity*, he has predicted from his theory, that I would find on examination the series of alternation of currents for the beginning induction which I have here given. I may, however, here add, it appears to me that this result might have been predicted without reference to any theory. There was no reason to suppose the induction at the beginning would be different in its nature from that at the ending, and therefore the series which would be produced from the former might be immediately inferred from that belonging to the latter, by recollecting that the direction of the induction at the beginning should be opposite to that at the ending. I do not wish it to be supposed, however, from this remark, that I had myself drawn any inference from my experiments as to the alternations of currents which might be produced by the beginning induction; the truth is that this action was so feeble with the arrangement of apparatus I employed, that I supposed it could not produce a series of currents of the different orders.

have found that a shock can be produced without using a coil, by arranging about ten elements of the battery in the form of a circle, and placing the helix within this. The shock was felt in the hands at the moment of closing the circuit, but the effect at opening the same was scarcely perceptible through the tongue. An attempt was also made to get indications of induction by placing the helix within a circle of dilute acid, connected with a battery instead of a coil, but the effect, if any, was very feeble.

29. I have shown in the second number of my Contributions, that if the body be introduced into a circuit with a battery of one hundred and twenty elements, without a coil, a thrilling sensation will be felt during the continuance of the current, and a shock will be experienced at the moment of interrupting the current by breaking the circuit at any point. This result is evidently due to the induction of a secondary current in the battery itself, and on this principle the remarkable physiological effects produced by Dr. Ure, on the body of a malefactor, may be explained. The body, in these experiments, was made to form a part of the circuit, with a compound galvanic apparatus in which a series of interruptions was rapidly made by drawing the end of a conductor over the edges of the plates of the battery. By this operation a series of induced currents must have been produced in the battery itself, the intensity of which was greater than that of the primary current.

30. In this connection I may mention that the idea has occurred to me that the intense shocks given by the electrical fish may possibly be from a secondary current, and that the great amount of nervous organization found in these animals may serve the purpose of a long conductor.* It appears to me, that in the present state of knowledge, this is the only way in which we can conceive of electricity so intense being produced in organs imperfectly insulated and immersed in a conducting medium. But we have seen that an original current of feeble intensity can induce, in a long wire, a secondary current capable of giving intense shocks, although the several strands of the wire are separated from each other only by a covering of cotton thread. Whatever may be the worth of this suggestion, the secondary current affords the means of imitating the phenomena of the

* Since writing the above, I have found that M. Masson has suggested the same idea, in an interesting thesis lately published.

shock from the electrical eel, as described by Dr. Faraday. By immersing the apparatus (Fig. 3) in a shallow vessel of water, the handles being placed at the two extremities of the diameter of the helix, and the hands plunged into the water parallel to a line joining the two poles, a shock is felt through the arms; but when the contact with the water is made in a line at right angles to the last, only a slight sensation is felt in each hand, but no shock.

31. Since the publication of my last paper, I have exhibited to my class the experiment (No. III, section 3) relative to the induction at a distance on a much larger scale. All my coils were united so as to form a single length of conductor of about four hundred feet, and this was rolled into a ring of five and a half feet in diameter, and suspended vertically against the inside of the large folding doors which separate the laboratory from the lecture room. On the other side of the doors, in the lecture room, and directly opposite the coil, was placed a helix, formed of upwards of a mile of copper wire, one sixteenth of an inch in thickness, and wound into a hoop of four feet in diameter. With this arrangement and a battery of one hundred and forty-seven square feet of zinc surface divided into eight elements, shocks were perceptible in the tongue when the two conductors were separated, to the distance of nearly seven feet; at the distance of between three and four feet the shocks were quite severe. The exhibition was rendered more interesting by causing the induction to take place through a number of persons standing in a row between the two conductors.

Section 2

On Apparently Two Kinds of Electro-Dynamic Induction

32. The investigations arranged under this head had their origin in the following circumstances. After the publication of my last paper, I received, through the kindness of Dr. Faraday, a copy of the fourteenth series of his Researches, and in this I was surprised to find a statement which appeared in direct opposition to one of the principal facts of my communication. In paragraph 59, I state in substance that when a plate of metal is interposed between the coil transmitting a galvanic current,

and the helix placed above it to receive the induction, the shock from the secondary current is almost perfectly neutralized. Dr. Faraday, in the extension of his new and ingenious views of the agency of the intermediate particles in transmitting induction, was led to make an experiment on the same point, and apparently under the same circumstances, he found that it "makes not the least difference whether the intervening space between the two conductors is occupied by such insulating bodies as air, sulphur, and shell-lac, or such conducting bodies as copper and other non-magnetic metals."

33. As the investigation of the fact mentioned above forms an important part of my paper, and is intimately connected with almost all the phenomena subsequently described in the communication I was, of course, anxious to discover the cause of so remarkable a discrepancy. There could be no doubt of the truth of my results, since a shock from a secondary current which would paralyze the arms was so much reduced by the interposition of plates of metal as scarcely to be felt through the tongue.

34. After some reflection, however, the thought occurred to me that induction might be produced in such a way as not to be affected by the interposition of a plate of metal. To understand this, suppose the end of a magnetic bar placed perpendicularly under the middle of a plate of copper, and a helix suddenly brought down on this; an induced current would be produced in the helix by its motion towards the plate, since the copper in this case could not screen the magnetic influence. Now, if we substitute for the magnet a coil through which a galvanic current is passing, the effect should be the same. The experiment was tried by attaching the ends of the helix to a galvanometer,* and the result was as I expected: when the coil was suddenly brought down on the plate the needle swung in one direction and when lifted up, in the other; the amount of the deflection being the same, whether the plate was interposed or not.

35. It must be observed in this experiment, that the plate was at rest, and consequently did not partake of the induction

* The arrangement will be readily understood by supposing, in Fig. 3, the handles removed, and the ends of the helix joined to the ends of the wire of a galvanometer; also, by a plate of metal interposed between the helix and the coil.

produced by the motion of the helix. From my previous investigations I was led to conclude that a different result would follow were a current also generated in the plate by simultaneously moving it up and down with the helix. This conclusion, however, was not correct, for on making the experiment I found that the needle was just as much affected when the plate was put in motion with the helix as when the latter alone was moved.

36. This result was so unexpected and remarkable that it was considered necessary to repeat and vary the experiment in several ways. First, a coil was interposed instead of the plate, but whether the coil was at rest or in motion with the helix, with its ends separated or joined, the effect on the galvanometer was still the same; not the least screening influence could be observed. In reference to the use of the coil in this experiment, it will be recollected that I have found this article to produce a more perfect neutralization than a plate.

37. Next, the apparatus remaining the same, and the helix at rest during the experiment, currents were induced in it by moving the battery attached to the coil up and down in the acid. But in this case, as in the others, the effect on the galvanometer was the same, whether the plate or the coil was interposed or not.

38. The experiment was also tried with magneto-electricity. For this purpose about forty feet of copper wire, covered with silk, were wound around a short cylinder of stiff paper, and into this was inserted a hollow cylinder of sheet copper, and into this again, a short rod of soft iron; when the latter was rendered magnetic, by suddenly bringing in contact with its two ends the different poles of two magnets, a current was, of course, generated in the wire, and this as before was found to affect the galvanometer to the same degree, when the copper cylinder was interposed, as when nothing but the paper intervened.

39. The last experiment was also varied by wrapping two copper wires of equal length around the middle of the keeper of a horse-shoe magnet, leaving the ends of the inner one projecting, and those of the outer attached to a galvanometer. A current was generated in each by moving the keeper on the ends of the magnet, but the effect on the galvanometer was not in the least diminished by joining the ends of the inner wire.

40. At first sight, it might appear that all these results are

effect of interposed coils and plates of metal. But it will be observed that in all the experiments just given, the induced currents are not the same as those described in my last communication. They are all produced by motion, and have an appreciable duration, which continues as long as the motion exists. They are also of low intensity, and thus far I have not been able to get shocks by any arrangement of apparatus from currents of this kind. On the other hand the currents produced at the moment of *suddenly* making or breaking a galvanic current, are of considerable intensity, and exist but for an instant. From these and other facts presently to be mentioned, I was led to suppose that there are two kinds of electro-dynamic induction; one of which can be neutralized by the interposition of a metallic plate between the conductors, and the other not.

41. In reference to this surmise, it became important to examine again all the phenomena of induction at suddenly making and breaking a galvanic current.* And in connection with this part of the subject I will first mention a fact which was observed in the course of the experiments given in the last section, on the direction of the induced currents of different orders. It was found that though the indications of the galvanometer were the same as those of the spiral, in reference to the direction of the induced currents, yet they were very different in regard to the intensity of the action. Thus, when the arrangement of the apparatus was such that the induction at making the battery circuit was so feeble as not to give the least magnetism to the needle, and so powerful at the ending as to magnetize it to saturation, the indication of the galvanometer was the same in both cases.

42. Also, similar results were obtained in comparing the shock and the deflection of the galvanometer. In one experiment, for example, the shock was so feeble at making contact that it could scarcely be perceived in the fingers, but so powerful at the breaking of the circuit as to be felt in the breast, yet the galvanometer was deflected about thirty-five degrees to the right, at the beginning of the current, and only an equal number of degrees to the left, at the ending of the same.

43. In another experiment, the apparatus being the same as

before, the magnetizing spiral and the galvanometer were both at once introduced into the circuit of the helix. A sewing needle being placed in the spiral, and the contact with the battery made, the needle showed no signs of magnetism, although the galvanometer was deflected thirty degrees. The needle being replaced, and the battery circuit broken, it was now found strongly magnetized, while the galvanometer was moved only about as much as before in the opposite direction.

44. Also, effects similar to those described in the last two paragraphs were produced when the apparatus was so arranged as to cause the induction at the beginning of the battery current to predominate. In this case the galvanometer was still almost equally affected at making and breaking battery contact, or any difference which was observed could be referred to a variation in the power of the battery during the experiment.

45. Another fact of importance belonging to the same class has been mentioned before (24), namely, that the actions of the currents of the third, fourth, and fifth orders produce a very small effect on the galvanometer, compared with that of the secondary current; and this is not on account of the diminishing power alone of the successive inductions, as will be evident from the following experiment: By raising the helix from the coil, in the arrangement of the apparatus for the secondary current, the shock was so diminished as to be inferior to one produced by the arrangement for a tertiary current, yet while with the secondary current the needle was deflected twenty-five degrees, with the tertiary it moved scarcely more than one degree; and with the currents of the fourth and fifth orders the deflections were still less, resembling the effect of a slight impulse given to the end of the needle.

46. With the light obtained from the foregoing experiments, I was the more fully persuaded that some new and interesting results might be obtained by a reëxamination of my former experiments, on the phenomena of the interposed plate of metal in the case where the induction was produced by making and breaking the circuit with a cup of mercury; and in this I was not disappointed. The coil (Fig. 3) being connected with a battery of ten elements, the shocks both at making and breaking the circuit, were very severe; and these as usual were

But when the galvanometer was introduced into the circuit instead of the body, its indications were the same whether the plate was interposed or not; or in other words the galvanometer indicated no screening, while, under the same circumstances, the shocks were neutralized.

47. A similar effect was observed when the galvanometer and the magnetizing spiral were together introduced into the circuit. The interposition of the plate entirely neutralized the magnetizing power of the spiral, in reference to tempered steel, while the deflections of the galvanometer were unaffected.

48. In order to increase the number of facts belonging to this class, the last experiments were varied in several ways; and first, instead of the hard steel needle, one of soft iron wire was placed in the spiral, with a small quantity of iron filings almost in contact with one of its ends. The plate being interposed, the small particles of iron were attracted by the end of the needle, indicating a feeble, temporary development of magnetism. Hence the current which moves the needle, and is not neutralized by the interposed plate, also feebly magnetizes soft iron, but not hard steel.

49. Again, the arrangement of apparatus being as in paragraph 46, instead of a plate of zinc, one of cast iron, of about the same superficial dimensions, but nearly half an inch thick, was interposed; with this, the magnetizing power of the spiral, in reference to tempered steel, was neutralized; and also the action of the galvanometer was much diminished.

50. Another result was obtained by placing in the circuit of the helix (Fig. 3), at the same time, the galvanometer, the spiral, and a drop of distilled water; with these the magnetizing power of the spiral was the same as without the water, but the deflection of the galvanometer was reduced from ten to about four degrees. In addition to these the body was also introduced into the same circuit; the shocks were found very severe, the spiral magnetized needles strongly, but the galvanometer was still less moved than before. The current of low intensity, which deflects the needle of the galvanometer in these instances, was partially intercepted by the imperfect conduction of the water and the body.

51. To exhibit the results of these experiments with still more precision, an arrangement of apparatus was adopted similar to

that used by Dr. Faraday, and described in the fourteenth series of his Researches, namely, a double galvanometer was formed of two separate wires of equal length and thickness, and wound together on the same frame; and also a double magnetizing spiral was prepared by winding two equal wires around the same piece of hollow straw. Coil No. 1, connected with the battery, was supported perpendicularly on a table, and coils Nos. 3 and 4 were placed parallel to this, one on each side, to receive the induction, the ends of these being so joined with those of the galvanometer and the spiral that the induced current from the one coil would pass through the two instruments, in an opposite direction to that of the current from the other coil. The two outside coils were then so adjusted, by moving them to and from the middle coil, that the induced currents perfectly neutralized each other in the two instruments, and the needle of the galvanometer and that in the spiral were both unaffected when the circuit of the battery was made and broken. With this delicate arrangement the slightest difference in the action of the two currents would be rendered perceptible; but when a zinc plate was introduced so as to screen one of the coils, the needle of the galvanometer still remained perfectly stationary, indicating not the least action of the plate while the needle in the spiral became powerfully magnetic. When, however, a plate of iron was interposed instead of the one of zinc, the needle of the galvanometer was also affected.

52. From the foregoing results it would seem that the secondary current, produced at the moment of the sudden beginning or ending of a galvanic current, by making and breaking contact with a cup of mercury, consists of two parts which possess different properties. One of these is of low intensity, can be interrupted by a drop of water, does *not* magnetize hardened steel needles, and is *not* screened by the interposition of a plate of any metal, except iron, between the conductors. The other part is of considerable intensity, is *not* intercepted by a drop of water, develops the magnetism of hardened steel, gives shocks and *is* screened or neutralized by a closed coil, or a plate of any kind of metal. Also, the induced current produced by moving a conductor towards or from a battery current, and that produced by the movement up and down of a battery in the acid, are of the nature of the first mentioned part, while the currents of the

third, fourth, and fifth orders partake almost exclusively of the properties of the second part.*

Postscript

53. The principal facts and conclusions of this section were announced to the Society in October, 1839, and again, in June last, presented in the form in which they are here detailed. Since then, however, I have had leisure to examine the subject more attentively, and after a careful comparison of these results with those before given, I have obtained the more definite views of the phenomena which are given in the following section.

SECTION 3

Theoretical Considerations Relating to the Phenomena Described in this and the Preceding Communications

Read November 20, 1840

54. The experiments given in No. III of my Contributions were merely arranged under different heads, and only such inferences drawn from them as could be immediately deduced without reference to a general explanation. The addition, however, which I have since made to the number of facts, affords the means of a wider generalization; and after an attentive consideration of all the results given in this and the preceding papers, I have come to the conclusion that they can all be referred to the simple laws of the induction at the beginning and the ending of a galvanic current.

55. In the course of these investigations the limited hypotheses which I have adopted have been continually modified by the development of new facts, and therefore my present views, with the further extension of the subject, may also require important corrections. But I am induced to believe, from its exact accordance with all the facts, so far as they have been

* (The above paper was reprinted in Silliman's *American Journal of Science*, April 1841, Vol. XLI, pp. 117–152. Also, in Sturgeon's *Annals of Electricity, etc.*, Vol. VII, pp. 21–56. Also in the *London and Edin-*

compared, that if the explanation I now venture to give be not absolutely true, it is so at least in approximation, and will therefore be of some importance in the way of suggesting new forms of experiment, or as a first step towards a more perfect generalization.

56. To render the laws of induction at the beginning and the ending of a galvanic current more readily applicable to the explanation of the phenomena, they may be stated as follows: 1. During the time a galvanic current is increasing in quantity in a conductor, it induces, or tends to induce, a current in an adjoining parallel conductor in an opposite direction to itself. 2. During the continuance of the primary current in full quantity, no inductive action is exerted. 3. But when the same current begins to decline in quantity, and during the whole time of its diminishing, an induced current is produced in an opposite direction to the induced current at the beginning of the primary current.

57. In addition to these laws, I must frequently refer to the fact, that *when the same quantity of electricity in a current of short duration is passed through a galvanometer, the deflecting force on the needle is the same, whatever be the intensity of the electricity*. By intensity is here understood the ratio of a given quantity of force to the time in which it is expended;* and according to this view the proposition stated is an evident inference from dynamic principles. But it does not rest on considerations of this kind alone, since it has been proved experimentally by Dr. Faraday, in the third series of his Researches.

58. In order to form a definite conception of the several conditions of the complex phenomena which we are about to investigate, I have adopted the method often employed in physical inquiries, of representing the varying elements of action by the different parts of a curve. This artifice has been of much assistance to me in studying the subject, and without the use of it at present, I could scarcely hope to present my views in an intelligible manner to the Society.

59. After making these preliminary statements, we will now proceed to consider the several phenomena; and first let us take the case in which the induction is most obviously produced in

* Or, more correctly speaking, the ratio of two quantities of the same

accordance with the laws as above stated (56), namely, by immersing a battery into the acid, and also by withdrawing it from the same. During the time of the descent of the battery into the liquid, the conductor connected with it is constantly receiving additional quantities of current electricity, and each of these additions produces an inductive action on the adjoining secondary conductor. The amount therefore of induced current produced during any moment of time will be just in proportion to the corresponding increase in the current of the battery during the same moment. Also, the amount of induction during any moment while the current of the battery is diminishing in quantity will be in proportion to the decrease during the same moment.

60. The several conditions of this experiment may be represented by the different parts of the curve, A, B, C, D, Fig. 17, in which the distances A*a*, A*b*, A*c*, represent the times during which the battery is descending to different depths into the acid, and the corresponding ordinates, *ag*, *bh*, *c*B, represent the amount of current electricity in the battery conductor corresponding to these times. The difference of the ordinates, namely, *ag*, *mh*, *n*B, express the increase in the quantity of the battery current during the corresponding moments of time represented by A*a*, *ab*, *bc*; and since the inductive action (59) is just in proportion to the increase, the same differences will also represent the amount of induced action exerted on the secondary conductor during the same moments of time.

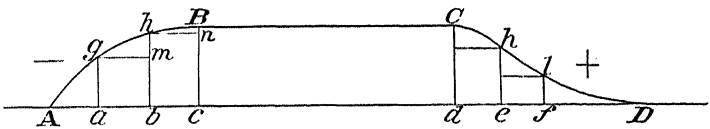

FIG. 17.

61. When the battery is fully immersed in the acid, or when the current in the conductor has reached its state of maximum quantity, and during the time of its remaining constant, no induction is exerted; and this condition is expressed by the constant ordinates of the part of the curve BC, parallel to the axis. Also, the inductive action produced by each diminution of the battery current, while the apparatus is in the progress of being

drawn from the acid, will be represented by the differences of the ordinates at the other end, CD, of the curve.

62. The sum of the several increments of the battery current, up to its full development, will be expressed by the ordinate *c*B, and this will therefore also represent the whole amount of the inductive action exerted in one direction at the beginning of the primary current; and, for the same reason, the equal ordinate, C*d*, will represent the whole induction in the other direction at the ending of the same current. Also, the whole time of continuance of the inductive action at the beginning and ending will be represented by A*c* and *d*D.

63. If we suppose the battery to be plunged into the acid to the same depth, but more rapidly than before, then the time represented by A*c*, will be diminished, while the whole amount of inductive force expended remains the same; hence, since the same quantity of force is exerted in a less time, a greater intensity of action will be produced (57), and consequently a current of more intensity, but of less duration, will be generated in the secondary conductor. The intensity of the induced currents will therefore evidently be expressed by the ratio of the ordinate *c*B to the abscissa A*c*. Or, in more general and definite terms, the intensity of the inductive action at any moment of time will be represented by the ratio of the rate of increase of the ordinate to that of the abscissa for that moment.*

64. It is evident from the last paragraph, that the greater or less intensity of the inductive action will be immediately presented to the eye by the greater or less obliquity of the several parts of the curve to the axis. Thus if the battery be suddenly plunged into the acid for a short distance, and then gradually immersed through the remainder of the depth, the varying action will be exhibited at once by the form of AB, the first part of the curve, Fig. 17. The steepness of the part A*g* will indicate an intense action for a short time A*a*, while the part *g*B denotes a more feeble induction during the time represented by *ac*. In

* According to the differential notation, the intensity will be expressed by $\frac{dy}{dx}$. In some cases the effect may be proportional to the intensity multiplied by the quantity, and this will be expressed by $\frac{dy^2}{dx}$, x and y representing as usual the variable abscissa and ordinate.

the same way by drawing up the battery suddenly at first, and afterwards slowly, we may produce an inductive action such as would be represented by the parts between C and D of the ending of the curve.

65. Having thus obtained representations of the different elements of action we are now prepared to apply these to the phenomena. And first, however, varied may be the intensity of the induction expressed by the different parts of the two ends of the curve, we may immediately infer that a galvanometer, placed in the circuit of the secondary conductor will be equally affected at the beginning and ending of the primary current; for, since the deflection of this instrument is due to the whole amount of a current, whatever may be its intensity (57), and since the ordinates cB and Cd, which represent the quantity of induction in the two directions, are equal, and consequently the amount of the secondary current, therefore the deflection at the beginning and ending of the battery current will in all cases be equal. This inference is in strict accordance with the results of experiment; for however rapidly or slowly we may plunge the battery into the acid and, however irregular may be the rate at which it is drawn out, still, if the whole effect be produced within the time of one swing of the needle, the galvanometer is deflected to an equal degree.

66. Again, the intensity of one part of the inductive action, for example that represented by Ag, may be supposed to be so great as to produce a secondary current capable of penetrating the body, and of thus producing a shock* while the other parts of the action represented by gB and CD, are so feeble as to affect the galvanometer only. We would then have a result the same as one of those given in the last section (42), and which was supposed to be produced by two kinds of induction; for if the shock were referred to as the test of the existence of an induced current, one would be found at the beginning only of the battery current, while, if the galvanometer were consulted, we would perceive the effects of a current as powerful at the ending as at the beginning.

67. The results mentioned in the last paragraph cannot be ob-

* The shock depends more on the intensity than on the quantity. See paragraph 13.

tained by plunging a battery into the acid; the formation of the current in this way is not sufficiently rapid to produce a shock. The example was given to illustrate the manner in which the same effect is supposed to be produced, in the case of the more sudden formation of a current, by plunging one end of a conductor into a cup of mercury permanently attached to a battery already in the acid, and in full operation. The current in this case — rapid as may be its development, cannot be supposed to assume *per saltum* its maximum state of quantity; on the contrary, from the general law of continuity, we would infer that it passes through all the intermediate states of quantity, from that of no current (if the expression may be allowed), to one of full development; there are, however, considerations of an experimental nature which would lead us to the same conclusion (18), (90), and also to the further inference that the *decline* of the current is not instantaneous. According to this view therefore the inductive action at the beginning and the ending of a primary current, of which the formation and interruption are effected by means of the contact with a cup of mercury, may also be represented by the several parts of the curve, Fig. 17.

68. We have now to consider how the rate of increase or diminution of the current, in the case in question, can be altered by a change in the different parts of the apparatus; and, first, let us take the example of a single battery and a short conductor, making only one or two turns around the helix; with this arrangement, a feeble shock, as we have seen (11), will be felt at the making, and also at the breaking of the circuit. In this case it would seem that almost the only impediment to the most rapid development of the current would be the resistance of the metal to conduction; and this we might suppose would be more rapidly overcome by increasing the tension of the electricity; and accordingly we find that if the number of elements of the battery be increased, the shock at making the circuit will also be increased, while that at breaking the circuit will remain nearly the same. To explain, however, this effect more minutely, we must call to mind the fact before referred to (17) that when the poles of a compound battery are not connected, the apparatus acquires an accumulation of electricity, which is discharged at the first moment of contact, and which in this case would more

rapidly develop the full current, and hence produce the more intense action on the helix at making the circuit.

69. The shock, and also the deflection of the needle, at breaking the circuit with a compound battery and a short coil (9) appear nearly the same as with a battery of a single element, because the accumulation just mentioned, in the compound battery, is discharged almost instantly, and according to the theory (71) of the galvanic current, leaves the constant current in the conductor nearly in the same state of quantity as that which would be produced by a battery of a single element; and hence the conditions of the ending of the current are the same in both cases. Indeed, in reference to the ending induction, it may be assumed as a fact which is in accordance with all the experiments (9, 13, 73, 74, 75, 76, etc.), as well as with theoretical considerations,* *that when the circuit is broken by a cup of mercury, the rate of the diminution of the current, within certain limits, remains the same, however the intensity of the electricity or the length of the conductor may be varied.*

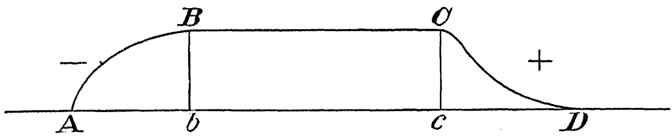

FIG. 18.

70. The several conditions of the foregoing examples are exhibited by the parts of the curves, Figs. 18 and 19. The gradual development of the current in the short conductor, with a single battery, and the gradual decline of the same, are represented by the gentle rise of AB and fall of CD, Fig. 18; while in the next Fig. (19) the sudden rise of AB indicates the intensity which produces the increased shock, after the number of elements of the battery has been increased. The accumulation of the electricity, which almost instantly subsides, is represented by the part B*ce*, Fig. 19, and from this we see at once, that although the shock is increased by using the compound battery, yet the needle of the galvanometer will be deflected only to the same number of degrees, since the parts B*c* and *ce* give inductive

actions in contrary directions, and both within the time of the single swing of the needle, and consequently they will neutralize each other. The resulting deflecting force will therefore be re-

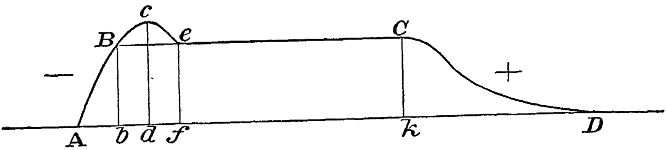

FIG. 19.

presented by *ef*, which is equal to C*k*, or to *b*B, in Fig. 19. The intensity of the shock at the breaking is represented as being the same in the two figures, by the similarity of the rate of descent of the part CD of the curve in each.

71. We have said (69) that the quantity of current electricity in a short conductor and a compound battery, after the first discharge, is nearly the same as with a single battery. The exact quantity according to the theory of Ohm, in a unit of length of the conductor, is given by the formula, —

$$\frac{n\text{A}}{rn + \text{R}}$$

In this, n represents the number of elements; A, the electromotive force of one element; r, the resistance to conduction of one element; and R, the length of the conductor, or rather, its resistance to conduction in terms of r. Now when R is very small in reference to rn, as is the case with a very short metallic conductor, it may be neglected, and then the expression becomes

$$\frac{n\text{A}}{rn} \text{ or } \frac{\text{A}}{r};$$

and since this expresses the quantity of current electricity in a unit of the length of the circuit, with either a single or a compound battery, therefore with a short conductor the quantity of current electricity in the two cases is nearly the same.

72. Let us next return to the experiment with a battery of a single element (68), and instead of increasing the intensity of the apparatus, as in the last example, let the length of the con-

ductor be increased; then the intensity of the shock at the beginning of the current, as we have seen (14), will be diminished, while that of the one at the ending will be increased. That the shock should be lessened at the beginning, by increasing the length of the conductor, is not surprising, since as we might suppose, the increased resistance to conduction would diminish the rapidity of the development of the current. But the secondary current, which is produced in the conductor of the primary current itself, as we have seen (19) is the principal cause which lessens the intensity of the shock; and the effect of this, as will be shown hereafter, may also be inferred from the principles we have adopted.

73. The explanation of the increased shock at the moment of breaking the circuit with the long conductor, rests on the assumption before mentioned (69), that the velocity of the diminution of a current is nearly the same in the case of a long conductor as in that of a short one. But to understand the application of this principle more minutely, we must refer to the change which takes place in the quantity of the current in the conductor by varying its length; and this will be given by another application of the formula before stated (71). This, in the case of a single battery, in which n equals unity becomes

$$\frac{A}{r + R}$$

and since this, as will be recollected, represents the quantity of current electricity in a unit of length of the conductor, we readily infer from it that by increasing the length of the conductor, or the value of R, the quantity of current in a unit of the length is lessened. And if the resistance of a unit of the length of the conductor were very great in comparison with that of r (the resistance of one element of the battery), then the formula would become

$$\frac{A}{R}$$

or the quantity in a single unit of the conductor would be inversely as its entire length, and hence the amount of current electricity in the whole conductor would be a constant quantity.

case in any of our experiments, since in no instance is the resistance of R very great in reference to r, and, therefore, according to the formula (73), the whole quantity of current electricity in a long conductor is always somewhat greater than in a short one.

74. Let us, however, in order to simplify the conditions of the induction at the ending of a current, suppose that the quantity in a unit of the conductor is inversely as its whole length, or in other words that the quantity of current electricity is the same in a long conductor as in a short one; and let us also suppose for an example that the length of the spiral conductor (Fig. 3) was increased from one spire to twenty spires; then, if the velocity of the diminution of the section of the current is the same (69) in the long conductor as in the short one, the shock which would be received by submitting the helix to the action of one spire of the long coil would be nearly of the same intensity as that from one spire of the short conductor; the quantity of induction, however, as shown by the galvanometer, should be nearly twenty times less; and these inferences I have found in accordance with the results of experiments (75). If, however, instead of placing the helix on one spire of the long conductor, it be submitted at once to the influence of all the twenty spires, then the intensity of the shock should be twenty times greater, since twenty times the quantity of current electricity collapses (if we may be allowed the expression) in the same time, and exerts at once all its influence on the helix. If in addition to this we add the consideration that the whole quantity of current electricity in a long conductor is greater than that in a short one (73), we shall have a further reason for the increase of the terminal shock, when we increase the length of the battery conductor.

75. The inference given in the last paragraph relative to the change in the quantity of the induction, but not in the intensity of the shock from a single spire, by increasing the whole length of the conductor, is shown to be true by repeating the experiment described in paragraph 13. In this, as we have seen, the intensity of the shock remained the same, although the length of the circuit was increased by the addition of coil No. 2. When, however, the galvanometer was employed in the same arrangement, the whole quantity of induction, as indicated by the deflection

of the needle, was diminished almost in proportion to the increased length of the circuit. I was led to make this addition to the experiment (13) by my present views.

76. The explanation given in paragraph 74 also includes that of the peculiar action of a long conductor, either coiled or extended, in giving shocks and sparks from a battery of a single element, discovered by myself in 1832 (see No. II). The induction in this case takes place in the conductor of the primary current itself, and the secondary current which is produced is generated by the joint action of each unit of the length of the primary current. Let us suppose for illustration that the conductor was at first one foot long, and afterwards increased to twenty feet. In the first case, because the short conductor would transmit a greater quantity of electricity, the secondary current produced by it would be one of considerable quantity, or power to deflect a galvanometer; but it would be of feeble intensity, for although the primary current would collapse with its usual velocity (69), yet, acting only on a foot of conducting matter, the effect (74) would be feeble. In the second case each foot of the twenty feet of the primary current would severally produce an inductive action of the same intensity as that of the short conductor, the velocity of collapse being the same; and as they are all at once exerted on the same conductor, a secondary current would result of twenty times the intensity of the current in the former case.

77. To render this explanation more explicit, it may be proper to mention that a current produced by an induction on one part of a long conductor of uniform diameter, must exist of the same intensity in every other part of the conductor; hence the action of the several units of length of the primary current must reenforce each other, and produce the same effect on its own conductor that the same current would if it were in a coil, and acting on a helix. I need scarcely add, that in this case, as in that given in paragraph 74, the whole amount of induction is greater with the long conductor than with the short one, because the quantity of current electricity is greater in the former than in the latter.

78. We may next consider the character of the secondary cur-

suppose) in the disturbance for an instant of the natural electricity of the metal, which subsiding leaves the conductor again in its natural state; and whether it is produced by the beginning or ending of a primary current, its nature, as we have seen (22), is the same. Although the time of continuance of the secondary current is very short, still we must suppose it to have some duration, and that it increases by degrees, to a state of maximum development, and then diminishes to the normal condition of the metal of the conductor; the velocity of its development like that of the primary current, will depend on the intensity of the action by which it is generated, and also perhaps in some degree, on the resistance of the conductor; while, agreeably to the hypothesis we have assumed (69), the velocity of its diminution is nearly a constant quantity, and is not affected by changes in these conditions; hence, if we suppose the induction which produces the secondary current to be sufficiently intense, the velocity of its development will exceed that of its diminution, as in the example of the primary current from the intense source of the compound battery of many elements. Now this is the case with the inductions which produce currents of the different orders, capable of giving shocks or of magnetizing steel needles; the secondary currents from these are always of considerable intensity, and hence their rate of development must be greater than that of their diminution, and, consequently, they may be represented by a curve of the form exhibited in Fig. 20, in which

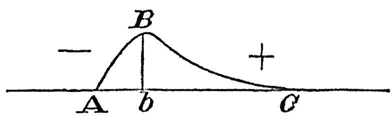

FIG. 20.

there is no constant part, and in which the steepness of AB is greater than that of BC. There are, however, other considerations which will be noticed hereafter (89), which may affect the form of the part BC of the curve, rendering it still more gradual in its descent, or in other words which tend to diminish the intensity of the ending induction of the secondary current.

79. It will be seen at once, by an inspection of the curve, that

called a tertiary current, is not of the same nature as that of a secondary current. Instead of being a single development in one direction, it consists of two instantaneous currents, one produced by the induction of AB, and the other by that of BC, in opposite directions, of equal quantities but of different intensities. The whole quantity of induction in the two directions, will each be represented by the ordinate B*b*, and hence they will nearly neutralize each other, in reference to their action on the galvanometer, in the circuit of the third conductor. I say they will *nearly* neutralize each other, because, although they are equal in quantity, they do not both act in absolutely the same moment of time. The needle will therefore be slightly affected; it will be impelled in one direction — say to the right, by the induction of AB, but, before it can get fairly under way, it will be arrested, and turned in the other direction, by the action of BC. This inference is in strict accordance with observation; the needle, as we have seen (24), starts from a state of rest, with a velocity which apparently would send it through a large arc, but before it has reached perhaps more than half a degree, it suddenly stops and turns in the other direction. As the needle is first affected by the action of AB, it indicates a current in the adverse direction to the secondary current.

80. Although the two inductions in the tertiary conductor nearly neutralize each other, in reference to the indications of the galvanometer, yet this is far from being the case with regard to the shocks, and the magnetization of steel needles. These effects may be considered as the results alone of the action of AB; the induction of BC being too feeble in intensity to produce a tertiary current of sufficient power to penetrate the body, or overcome the coercive power of the hardened steel. Hence, in reference to the shock, and magnetization of the steel needle, we may entirely neglect the action of BC, and consider the tertiary excitement as a single current, produced by the action AB; and because this is the beginning induction (56), the tertiary current must be in an opposite direction to the secondary. For a similar reason a current of the third order should produce in effect a single current of the fourth order, in a direction opposite to that of the current which produced it, and so on; we have here therefore a simple explanation of the

the currents of the different orders, as given in this and the preceding paper. (See paragraph 25.)

81. The operation of the interposed plate (32, 47, 48, etc.), in neutralizing the shock, and not affecting the galvanometer, can also be readily referred to the same principles. It is certain that an induced current is produced in the plate (No. III, 64), and that this must re-act on the secondary, in the helix, but it should not alter the total amount of this current, since for example at the ending induction, the same quantity of current is added to the helix while the current in the plate is decreasing, as is subtracted while the same current is increasing. To make this more clear, let the inductive actions of the interposed current be represented by the parts of the curve, Fig. 20. The induction represented by AB will react on the current in the helix and diminish its quantity by an amount represented by the ordinate B*b*; but the induction represented by BC, will act in the next moment, on the same current, and increase its quantity by an equal amount, as represented by the same ordinate B*b*; and since both actions take place within a small part of the time of a single swing of the needle, the whole deflection will not be altered, and consequently, as far as the galvanometer is concerned, the interposition of the plate will have no perceptible effect.

82. But the effect of the plate on the shock, and on the magnetization of tempered steel, should be very different; for, although the quantity of induction in the helix may not be changed, yet its intensity may be so reduced, by the adverse action of the interposed current, as to fall below that degree which enables it to penetrate the body, or overcome the coercive force of the steel. To understand how this may be, let us again refer, for example, to the induction which takes place at the ending of a battery current; this will produce, in both the helix and the plate, a momentary current in the direction of the primary current which we have called *plus*; the current in the plate will react on the helix, and tend to produce in it two inductions, which as before may be represented by AB, and BC, of the curve, Fig. 20; the first of these (AB) will be an intense action (78), in the *minus* direction, and will therefore tend to neutralize the intense action of the primary current on the helix; the second (BC) will add to the helix an equal

quantity of induced current, but of a much more feeble intensity, and hence the resulting current in the helix will not be able to penetrate the body; no shock will be perceived, or at least a very slight one, and the phenomena of screening will be exhibited.

83. When the plate of metal is placed between the conductors of the second and third orders, or between those of the third and fourth, the action is somewhat different, although the general principle is the same. Let us suppose the plate interposed between the second and third conductors; then the helix, or third conductor, will be acted on by four inductions, two from the secondary current and two from the current in the plate. The direction and character of these will be as follows, on the supposition that the direction of the secondary current is itself *plus:*

The beginning secondary . .	intense and .	*minus.*
The ending secondary . . .	feeble and .	*plus.*
The beginning interposed . .	intense and .	*plus.*
The ending interposed . . .	feeble and .	*minus.*

Now if the action, on the third conductor, of the first and third of the above inductions be equal in intensity and quantity, they will neutralize each other; and the same will also take place with the action of the second and fourth, if they be equal, and hence in this case, neither shock nor motion of the needle of the galvanometer would be produced. If these inductions be not precisely equal, then only a partial neutralization will take place, and the shock will be merely diminished in power; and also the needle will perhaps be very slightly affected.

84. If in the foregoing exposition we throw out of consideration the actions of the feeble currents which cannot pass the body, and which consequently are not concerned in producing the shock, then the same explanation will still apply which was given in the last paper (No. III, 94) namely, in the above example, the helix is acted on by the minus influence of the secondary, and the plus influence of the interposed current.

85. We are now prepared to consider the effect on the helix (Fig. 3) of the induced currents produced in the conductor of the primary current itself. These are true secondary currents, and are almost precisely the same in their action as those in the

interposed plate. Let us first examine the induced currents at the beginning of the primary, in the case of a long coil and a battery of a single element. Its action on the helix may be represented by the parts of the curve, Fig. 20. The first part, AB, will produce an intense induction opposite to that of the primary current; and hence the action of the two will tend to neutralize each other, and no shock, or a very feeble one, will be produced. The ending action of the same induced current, which is represented by BD, restores to the helix the same quantity of current electricity (but in a feeble state) which was neutralized by AB, and hence the needle of the galvanometer will be as much affected as if this current did not exist. These inferences perfectly agree with the experiment given in paragraph 19. In this, when the ends of the interposed coil were joined so as to neutralize the induced current in the long conductor, the shock at the beginning of the primary current was nearly as powerful as with a short conductor, while the amount of deflection of the galvanometer was unaffected by joining the ends of the same coil.

86. At first sight it might appear that any change in the apparatus which may tend to increase the induction of the primary current (16) would also tend to increase in the same degree the adverse secondary in the same conductor; and that hence the neutralization mentioned in the last paragraph would take place in all cases; but we must recollect that if a more full current be suddenly formed in a conductor of a given thickness, the adverse current will not have as much space as it were for its development, and therefore will have less power in neutralizing the induction of the primary than before. But there is another and perhaps a better reason, in the consideration that in the case of the increase of the number of elements of the battery, although the rapidity of the development of the primary current is greater, yet the increased resistance which the secondary meets with, in its motion against the action of the several elements, will tend to diminish its effect. Also by diminishing the length of the primary current, we must diminish (76) the intensity of the secondary, so that it will meet with more resistance in passing the acid of the single battery, and thus its effects be diminished.

87. The action of the secondary current in the long coil at

the *ending* of the primary current, should also at first sight produce the same screening influence as the current in the interposed plate; but on reflection it will be perceived that its action in this respect must be much more feeble than that of the similar current at the beginning; the latter is produced at the moment of making contact, and hence it is propagated in a continuous circuit of conducting matter, while the other takes place at the *rupture* of the circuit, and must therefore be rendered comparatively feeble by being obliged to pass through a small portion of heated air; very little effect is therefore produced on the helix by this induction (19). The fact that this current is capable of giving intense shocks, when the ends of a long wire which is transmitting a primary current, are grasped at the time of breaking the circuit is readily explained, since in this case the body forms with the conductor a closed circuit, which permits the comparatively free circulation of the induced current.

88. It will be seen that I have given a peculiar form to the beginning and ending of the curves, Fig. 17, 18, etc. These are intended to represent the variations which may be supposed to take place in the rate of increase and decrease of the quantity of the current, even in the case where the contact is made and broken with mercury. We may suppose, from the existence of analogous phenomena in magnetism, heat, etc., that the development of the current would be more rapid at first than when it approximates what may be called the state of current saturation, or when the current has reached more nearly the limit of capacity of conduction of the metal. Also, the decline of the current may be supposed to be more rapid at the first moment, than after it has lost somewhat of its intensity, or sunk more nearly to its normal state. These variations are indicated by the rapid rise of the curve, Fig. 17, from A to *g*, and the more gradual increase of the ordinates from *h* to B; and by the rapid diminution of the ordinates between C and *l*, and the gradual decrease of those towards the end of the curve.

89. These more minute considerations, relative to the form of the curve, will enable us to conceive, how the time of the ending of the secondary current, as we have suggested (78), may be prolonged beyond that of the natural subsidence of the dis-

rent depends. If the development of the primary current is produced by equal increments in equal times, as would be the case in plunging the battery (59) into the acid with a uniform velocity, then the part AB of the curve, Fig. 17, would be a straight line, and the resulting secondary current, after the first instant, would be one of constant quantity during nearly the whole time represented by A*c*; but if the rate of the development of the primary current be supposed to vary in accordance with the views we have given in the last paragraph, then the quantity of the secondary current will begin to decline before the termination of the induction, or as soon as the increments of the primary begin to diminish; and hence the whole time of the subsidence of the secondary will be prolonged, or the length of *b*C, Fig. 20, will be increased, the descent of BC be more gradual, and the intensity of the ending induction of the secondary current be diminished (see last part of paragraph 78).

90. Besides the considerations we have mentioned (88), there are others of a more obvious character, which would also appear to affect the form of particular parts of the curve. And first, we might perhaps make a slight correction in the drawings of Figs. 17, 18, etc., at the point A, in consideration of the fact that the very first contact of the end of the conductor with the surface of the mercury is formed by a point of the metal, and hence the increment of development should be a little less rapid at the first moment than after the contact has become larger; or in other words, the curve should perhaps start a little less abruptly from the axis at the point A. Also, Dr. Page has stated* that he finds the shock increased by spreading a stratum of oil over the surface of the mercury; in this case it is probable that the termination of the current is more sudden, on account of the prevention of the combustion of the metal by means of the oil, and the fact that the end of the conductor is drawn up into a non-conducting medium.

91. The time of the subsidence of the current when the circuit is broken by means of a surface of mercury, is very small, and probably does not exceed the ten-thousandth part of a second, but even this is an appreciable duration, since I find that the spark at the ending presents the appearance of a band of light

of considerable length, when viewed in a mirror revolving at the rate of six hundred times in a second; and I think the variations in the time of the ending of a current under the different conditions may be detected by means of this instrument.

92. Before concluding this communication, I should state that I have made a number of attempts to verify the suggestion given in my last paper (No. III, 127) that an inverse induction is produced by a galvanic current by a change in the distance of the conductors, but without success. These attempts were made before I had adopted the views given in this section, and since then I have found (80) a more simple explanation of the alternation of the currents.

93. In this number of my Contributions, the phenomena exhibited by the galvanic apparatus have alone been discussed. I have, however, made a series of experiments on the induction from ordinary electricity, and the re-action of soft iron on currents; and I think that the results of these can also be referred to the simple principles adopted in this paper; but they require further examination before being submitted to the public.

On Induction from Ordinary Electricity; and on the Oscillatory Discharge

CONTENTS

Contributions to Electricity and Magnetism

No. V

On Induction from Ordinary Electricity; and on the Oscillatory Discharge *

By JOSEPH HENRY

(*Proceedings of the American Philosophical Society*, Vol. II, pp. 193–196, June 17, 1842; *Scientific Writings*, Vol. I, p. 200.)

Professor Henry presented the record of a series of experiments on induction from ordinary electricity, as the fifth number of his Contributions to Electricity and Magnetism. Of these experiments he gave an oral account, of which the following is the substance.

In the third number of his Contributions he had shown on this subject: 1. That the discharge of a Leyden battery through a conductor, developed in an adjoining parallel conductor an induced current, analogous to that which, under similar circumstances, is produced by a galvanic current. 2. That the direction of the induced current, as indicated by the polarity given to a steel needle, changes its sign with a change of distance of the two conductors, and also with a change in the quantity of the discharge of electricity. 3. That when the induced current is made to act on a third conductor, a second induced current is developed, which can again develop another, and so on through a series of successive inductions. 4. That when a plate of metal is interposed between any two of the consecutive conductors, the induced current is neutralized by the adverse action of a current in the plate.

The direction of the induced currents in all the author's

* The full Memoir was not printed in the *Transactions of the American*

experiments was indicated by the polarity given to steel needles enclosed in a spiral, the wire of which formed a part of the circuit. But some doubts were reasonably entertained of the true indications of the direction of a current by this means, since M. Savary had announced in 1826, that when several needles are placed at different distances above a wire, through which the discharge of a Leyden battery is passed, they are magnetized in different directions, and that by constantly increasing the discharge through a spiral, several reversions of the polarity of the contained needles are obtained.

It was therefore very important before attempting further advances in the discovery of the laws of the phenomena, that the results obtained by M. Savary should be carefully studied; and accordingly the first experiments of the new series relate to the repetition of them. The author first attempted to obtain them by using needles of a larger size, Nos. 3 and 4, such as he had generally employed in all his previous experiments; but although nearly a thousand needles were magnetized in the course of the experiments, he did not succeed in getting a single change in the polarity. The needles were always magnetized in a direction conformable to the direction of the electrical discharge. When, however, very fine needles were employed he did obtain several changes in the polarity in the case of the spiral, by merely increasing the quantity of the electricity, while the direction of the discharge remained the same.

This anomaly which has remained so long unexplained, and which at first sight appears at variance with all our theoretical ideas of the connection of electricity and magnetism, was after considerable study satisfactorily referred by the author to an action of the discharge of the Leyden jar which had never before been recognized. The discharge, whatever may be its nature, is not correctly represented (employing for simplicity the theory of Franklin) by the single transfer of an imponderable fluid from one side of the jar to the other; the phenomena require us to admit *the existence of a principal discharge in one direction, and then several reflex actions backward and forward, each more feeble than the preceding, until the equilibrium is obtained.* All the facts are shown to be in accordance with this hypothesis, and a ready explanation is afforded by it of a

on electricity, but which have until this time remained unexplained.

The same action is evidently connected with the induction of a current on its own conductor, in the case of an open circuit, such as that of the Leyden jar, in which the two ends of the conductor are separated by the thickness of the glass. And hence, if an induced current could be produced in this case, one should also be obtained in that of a second conductor, the ends of which are separated; and this was detected by attaching to the ends of the open circuit a quantity of insulated metal, or by connecting one end with the earth.

The next part of the research relates to a new examination of the phenomena of the change in the direction of the induced currents, with a change of distance, etc. These are shown to be due to the fact that the discharge from a jar does not produce a single induced current in one direction, but several successive currents in opposite directions. The effect on the needle is principally produced by two of these: the first is the more powerful and in the adverse direction with that of the jar; the second is less powerful, and in the same direction with that of the jar. To explain the change of polarity, let us suppose the capacity of the needle to receive magnetism to be represented by ± 10, while the power of the first induced current to produce magnetism is represented by -15, and that of the second by $+12$; then the needle will be magnetized to saturation or to -10, by the first induced current, and immediately afterwards all this magnetism will be neutralized by the adverse second induction, and a power of $+2$ will remain; so that the polarity of the needle in this case will indicate an induced current in the same direction as that of the jar. Next, let the conductors be so far separated, or the charge so much diminished, that the power of the first current to develop magnetism may be reduced to -8, while that of the second current is reduced to $+6$, the magnetic capacity of the needle remaining the same. It is evident then that the first current will magnetize the needle to -8, and that the second current will immediately afterwards neutralize 6 of this, and consequently the needle will retain a magnetism of -2, or will indicate an induced current in an opposite direction to that of the jar.

gations, a remarkable result was obtained in regard to the distance at which inductive effects are produced by a very small quantity of electricity; a single spark from the prime conductor of the machine, of about an inch long, thrown on the end of a circuit of wire in an upper room, produced an induction sufficiently powerful to magnetize needles in a parallel circuit of wire placed in the cellar beneath, at a perpendicular distance of thirty feet with two floors and ceilings, each fourteen inches thick, intervening. The author is disposed to adopt the hypothesis of an electrical *plenum*, and from the foregoing experiment it would appear that the transfer of a single spark is sufficient to disturb perceptibly the electricity of space throughout at least a cube of 400,000 feet of capacity; and when it is considered that the magnetism of the needle is the result of the difference of two actions, it may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from a flint and steel in the case of light.

The author next alludes to a proposition which he advanced in the second number of his Contributions, namely, that the phenomena of dynamic induction may be referred to the known electrical laws, as given by the common theories of electricity; and he gives a number of experiments to illustrate the connection between statical and dynamical induction.

The last part of the series of experiments relates to induced currents from atmospheric electricity. By a very simple arrangement, needles are strongly magnetized in the author's study, even when the flash is at the distance of seven or eight miles, and when the thunder is scarcely audible. On this principle he proposes a simple self-registering electrometer, connected with an elevated exploring-rod.

Biographical Sketch

Joseph Henry was born in Albany, in the State of New York, December 17, 1799, and died in Washington, D. C., May 13, 1878. His scientific work began with his appointment, in 1826, to the chair of Mathematics and Natural Philosophy in the Academy at Albany. In 1832 his fame was so great that he was called to be Professor of Natural Philosophy in the College of New Jersey at Princeton. In 1846 he was elected to be the

C. x. D.

Secretary and Director of the Smithsonian Institution in
ington, a position which he held until his death. Among
offices of honor which he occupied were Chairman of the
ed States Lighthouse Board, President of the Washington
osophical Society, and President of the National Academy
ciences.

was while he was at the Albany Academy that he devised
intensity" and "quantity" magnets, for which he wound
s or bobbins of wire around the ends of a piece of soft iron
into the shape of a horse-shoe. This was the first use of a
of wire in electro-magnetism. He showed that an in-
ty magnet could be used at a distance, thus making the
very of the essential principles of the telegraph; and he
ed further that he had a clear understanding of what is
called Ohm's Law. He made the first magneto-electric
r, and began the series of investigations which ended in
iscovery of self- and mutual induction in 1829 and 1830.
moving to Princeton, in 1832, he continued his work on
ro-magnetic induction, proving the existence of currents of
third, fourth, etc., orders. He investigated also the dis-
ge of a Leyden jar, proved that it was oscillatory in charac-
and showed that its inductive effects could be detected at
stance of two hundred feet, thus clearly establishing the
ence of electro-magnetic waves.

1846, Henry accepted the office of Secretary and Director
e Smithsonian Institution, and displayed in its establish-
, and management wonderful executive ability. His most
rtant scientific work was now in connection with researches
ound, and sound propagation. Under his direction, the
hsonian Institution established a comprehensive system of
raphic meteorology throughout the United States, made
ther maps," and prepared weather predictions.

enry's Scientific Writings have been collected and published
vo volumes by the Smithsonian Institution, Washington,
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INDEX

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